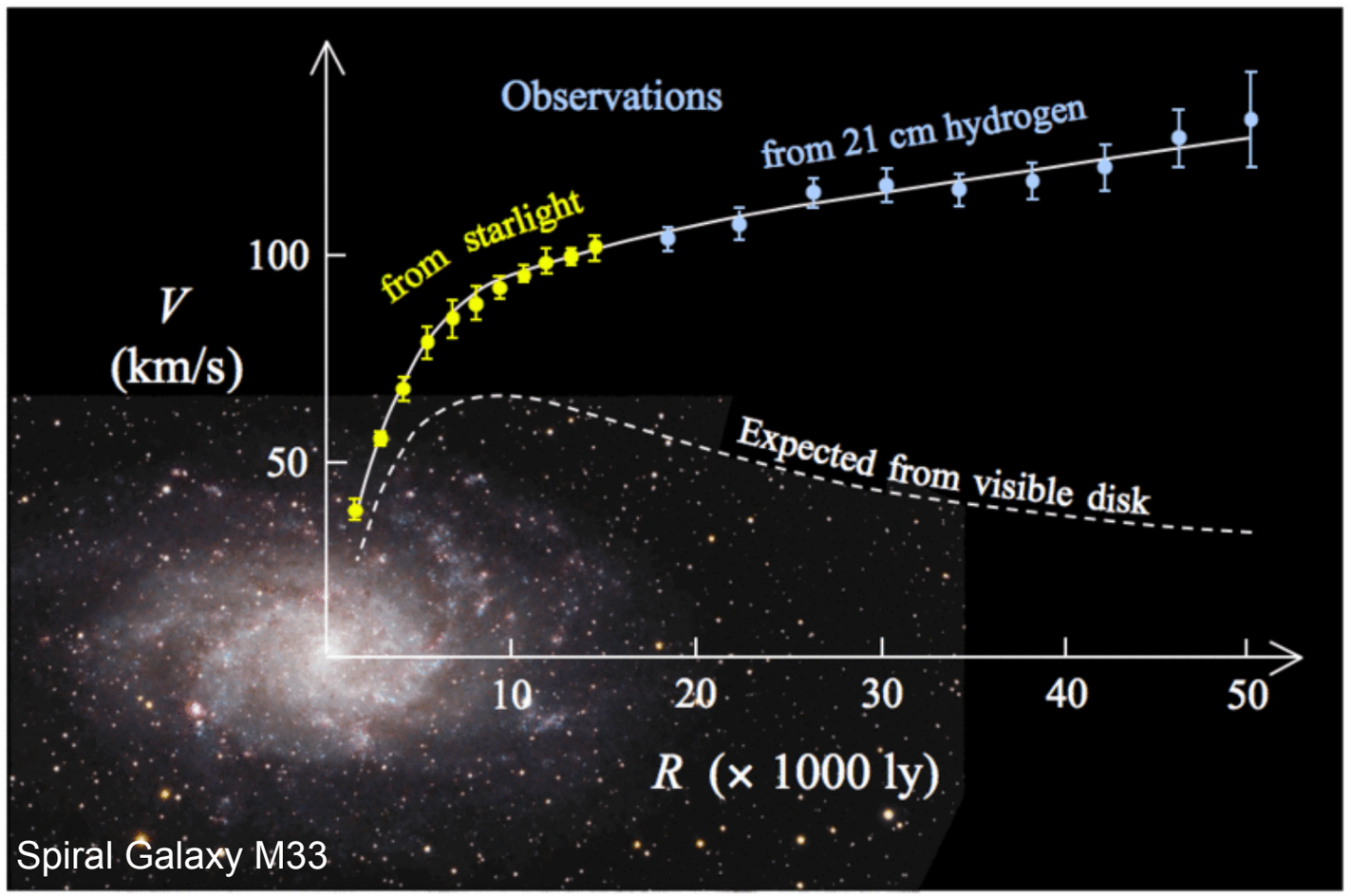
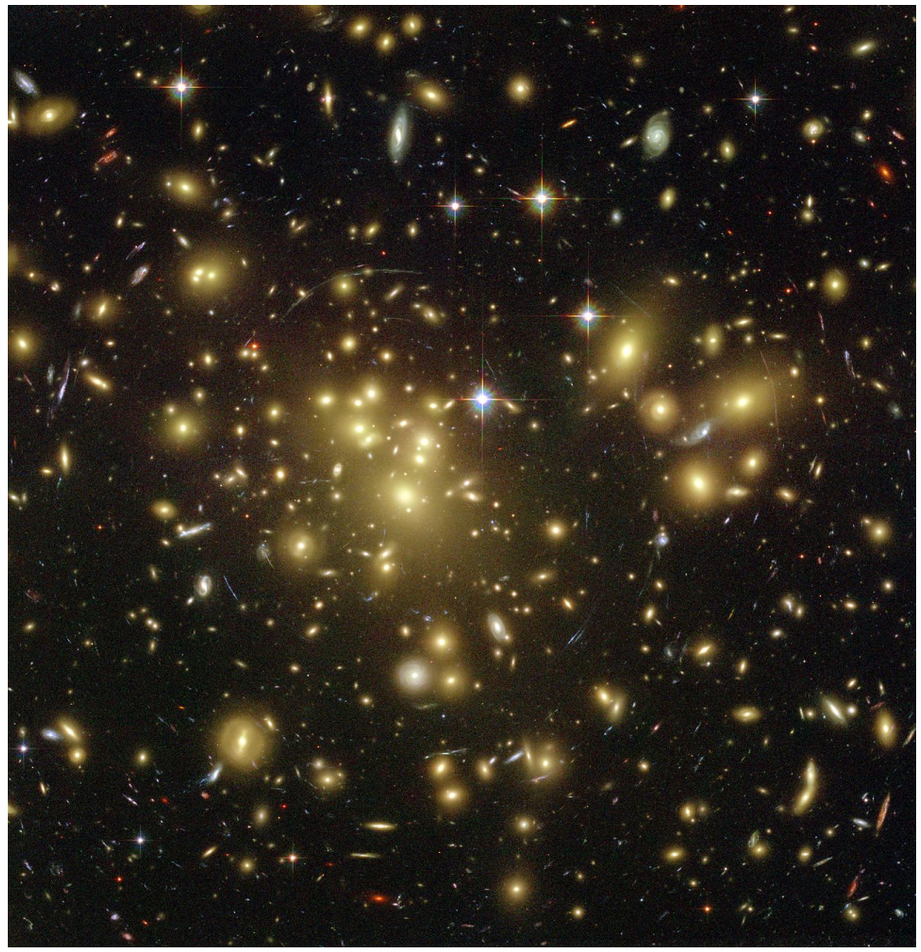
NEWS-G: Search for Light Dark Matter with Spherical Proportional Counters

Konstantinos Nikolopoulos
University of Birmingham

March 18, 2021
CPAD Instrumentation Frontier Workshop 2021, Stony Brook, USA

Dark Matter





- **Evidence from gravitational interactions over many distance scales**
  - Rotational curves
  - Gravitational lensing
  - Cosmic microwave background
  - Large scale structure formation
- **Corresponds to 85% of the matter content of the universe**

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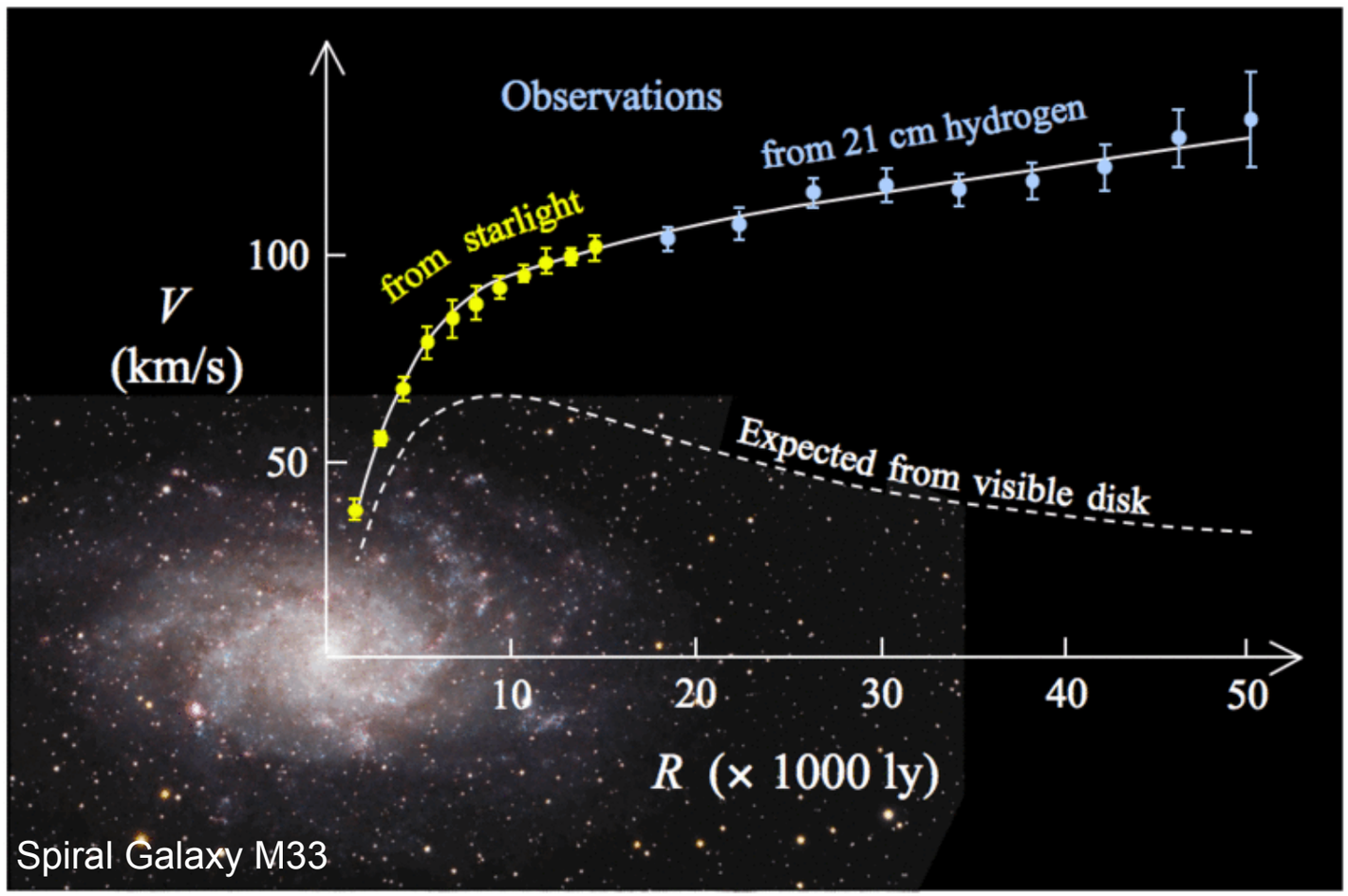

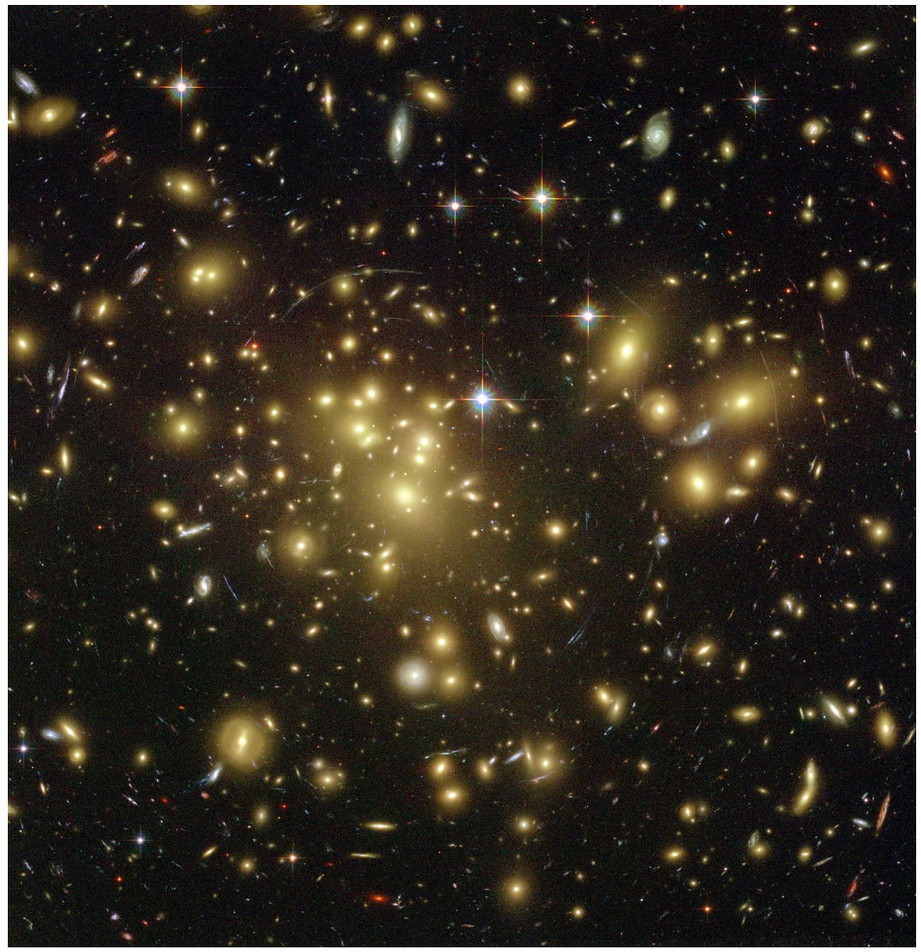

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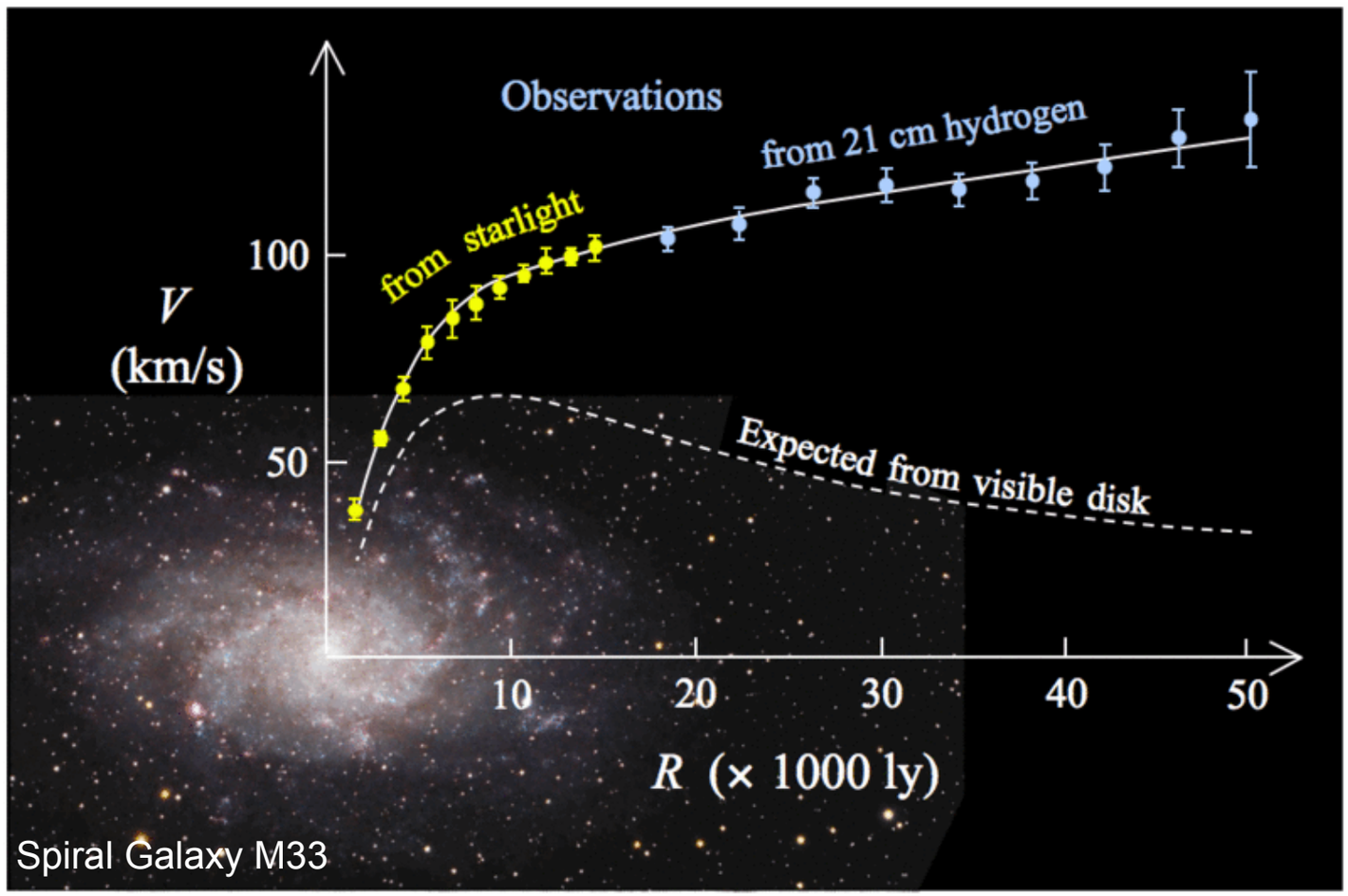
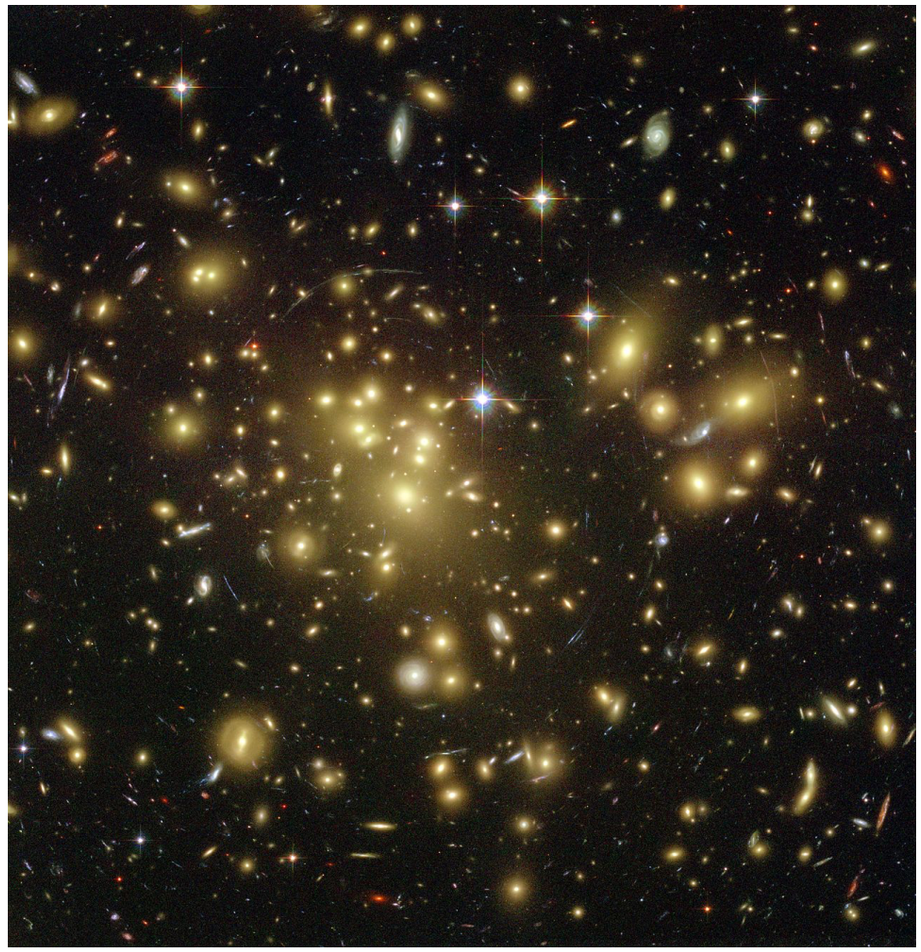
Dark Matter Particle (X^0)

X^0 mass: $m = ?$
X^0 spin: $J = ?$
X^0 parity: $P = ?$
X^0 lifetime: $\tau = ?$
X^0 scattering cross-section on nucleons: $?$
X^0 production cross-section in hadron colliders: $?$
X^0 self-annihilation cross-section: $?$

Dark Matter





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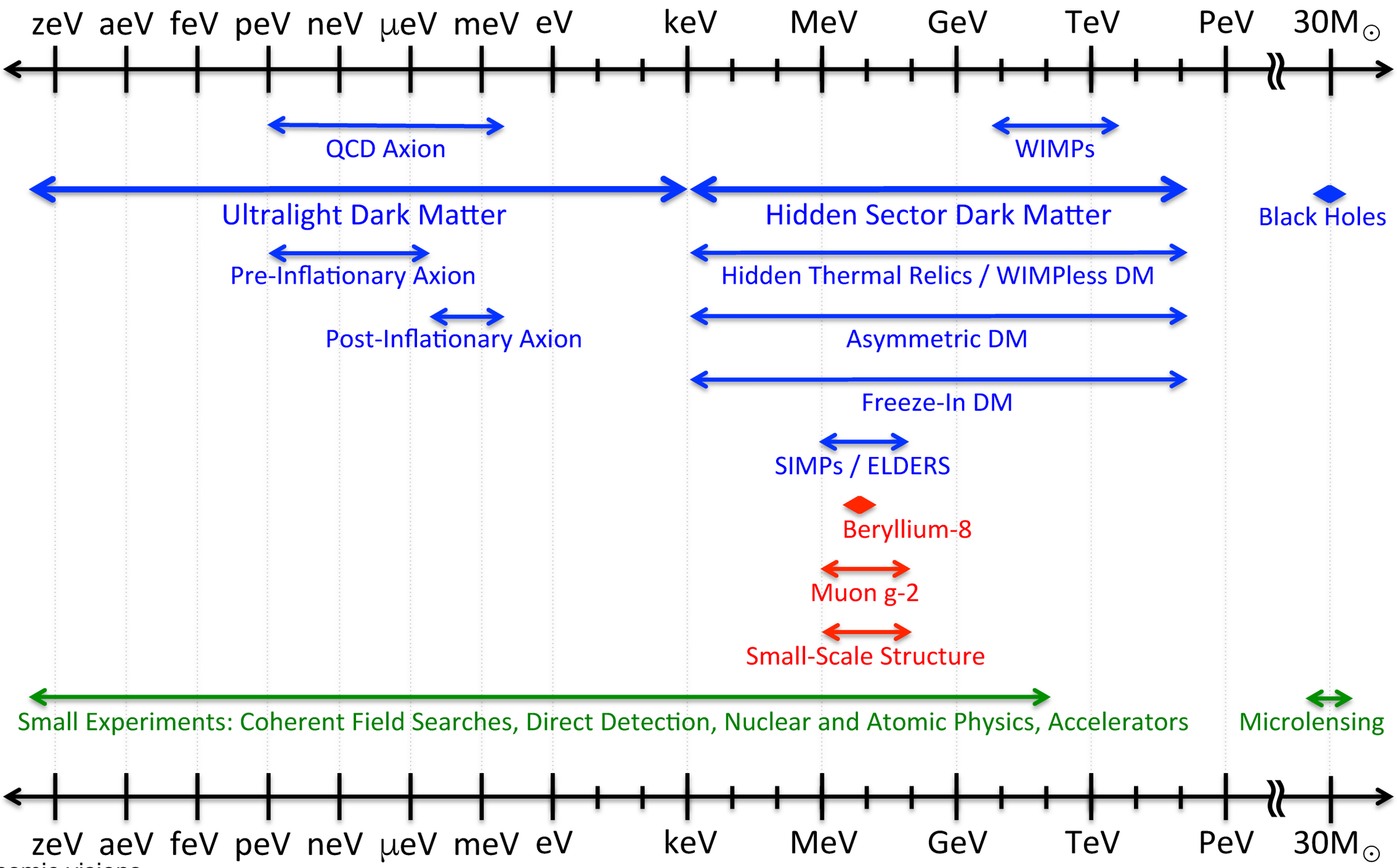
X^0 self-annihilation cross-section: ?

No known particle fits the bill!

Wide field of possibilities!

Dark Sector Candidates, Anomalies, and Search Techniques



Cosmic visions
arXiv:1707.04591

Wide field of possibilities!

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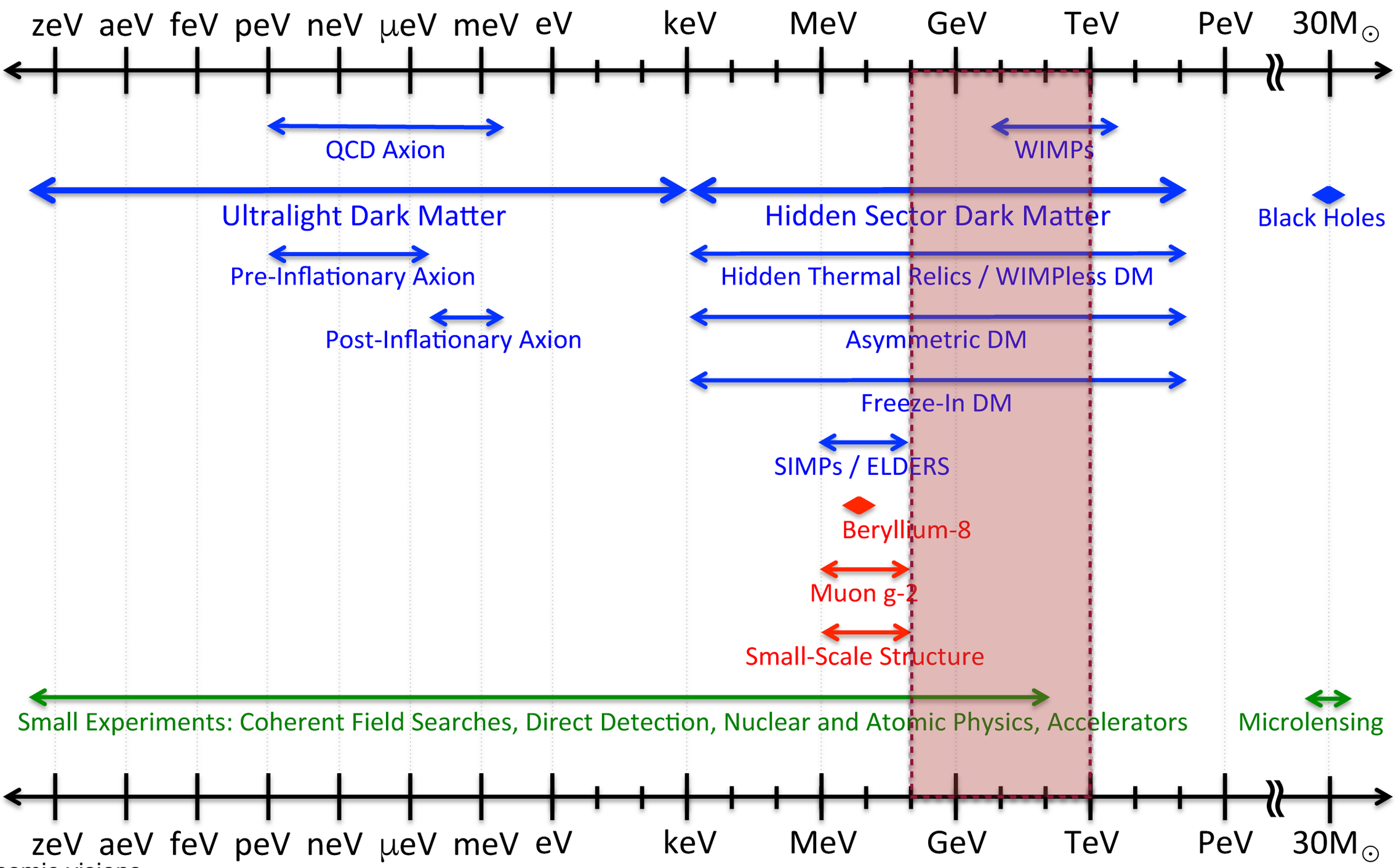

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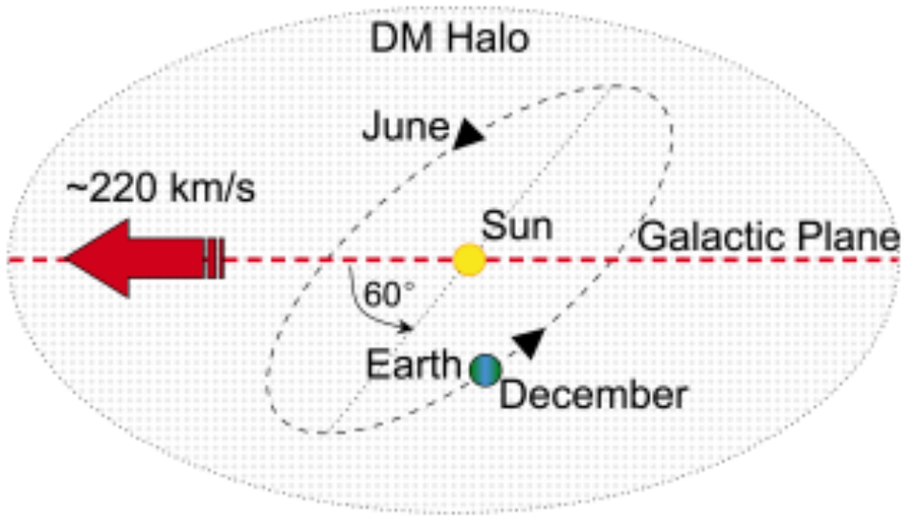
Dark Matter Direct Detection



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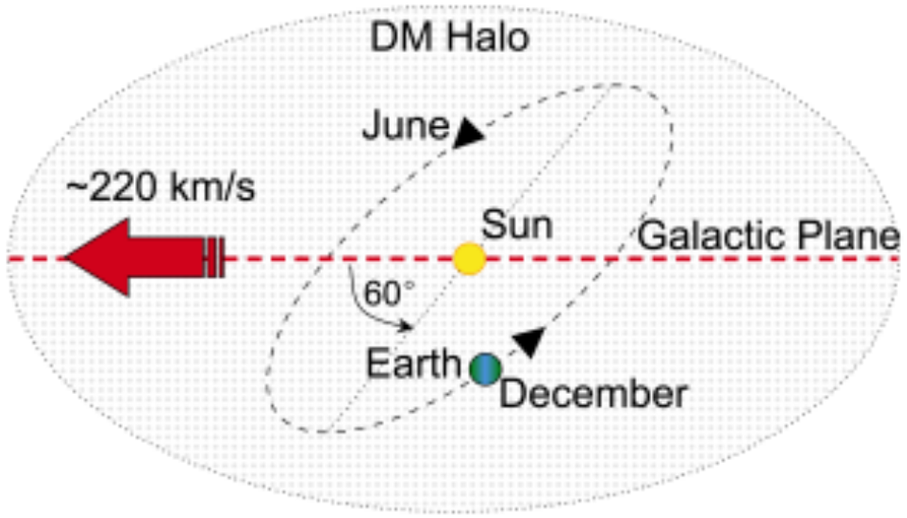

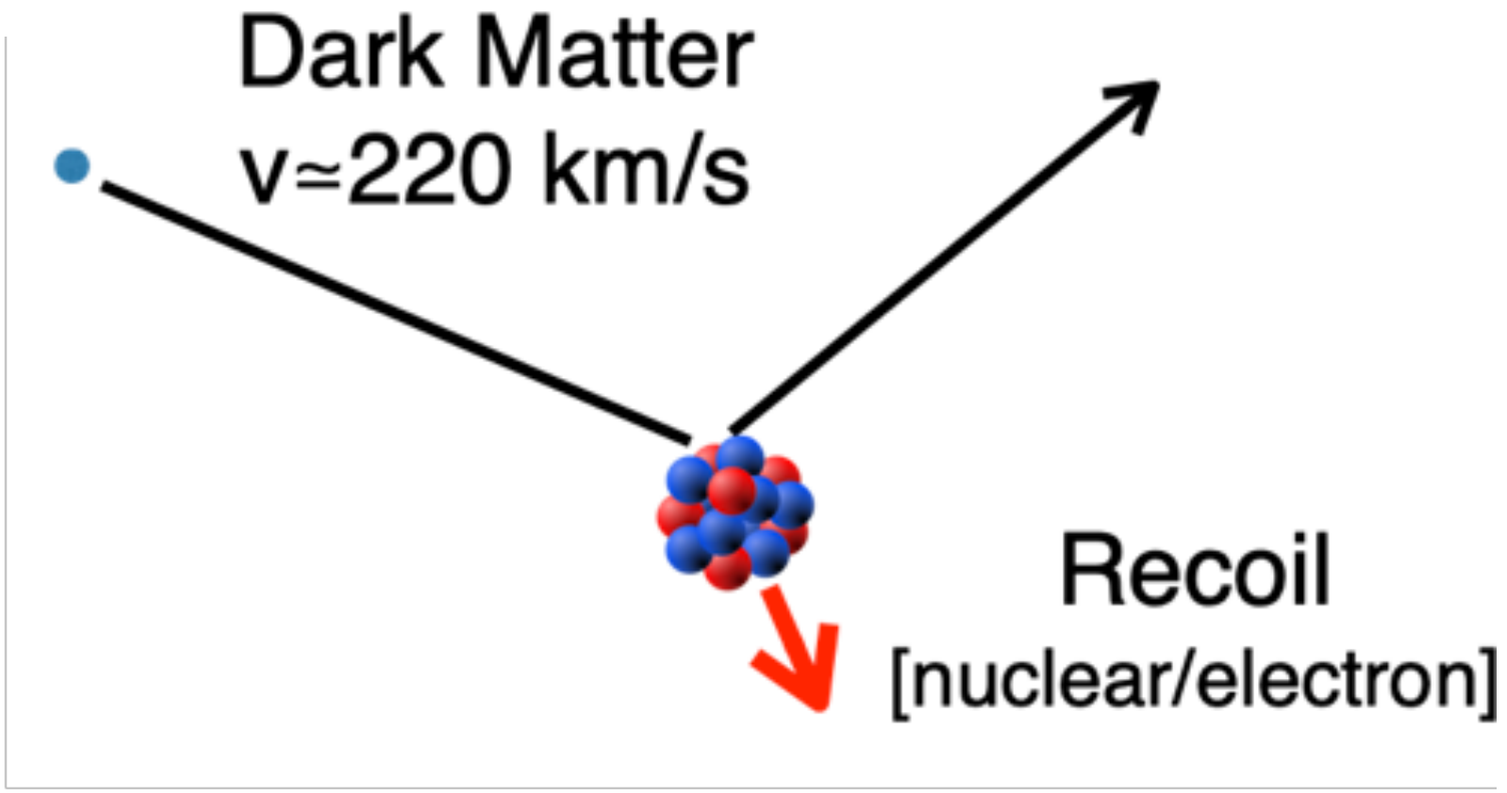

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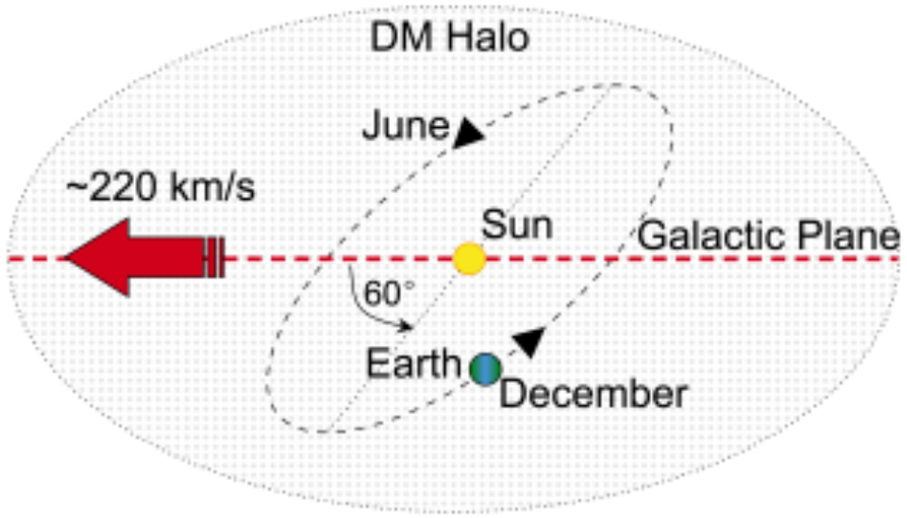
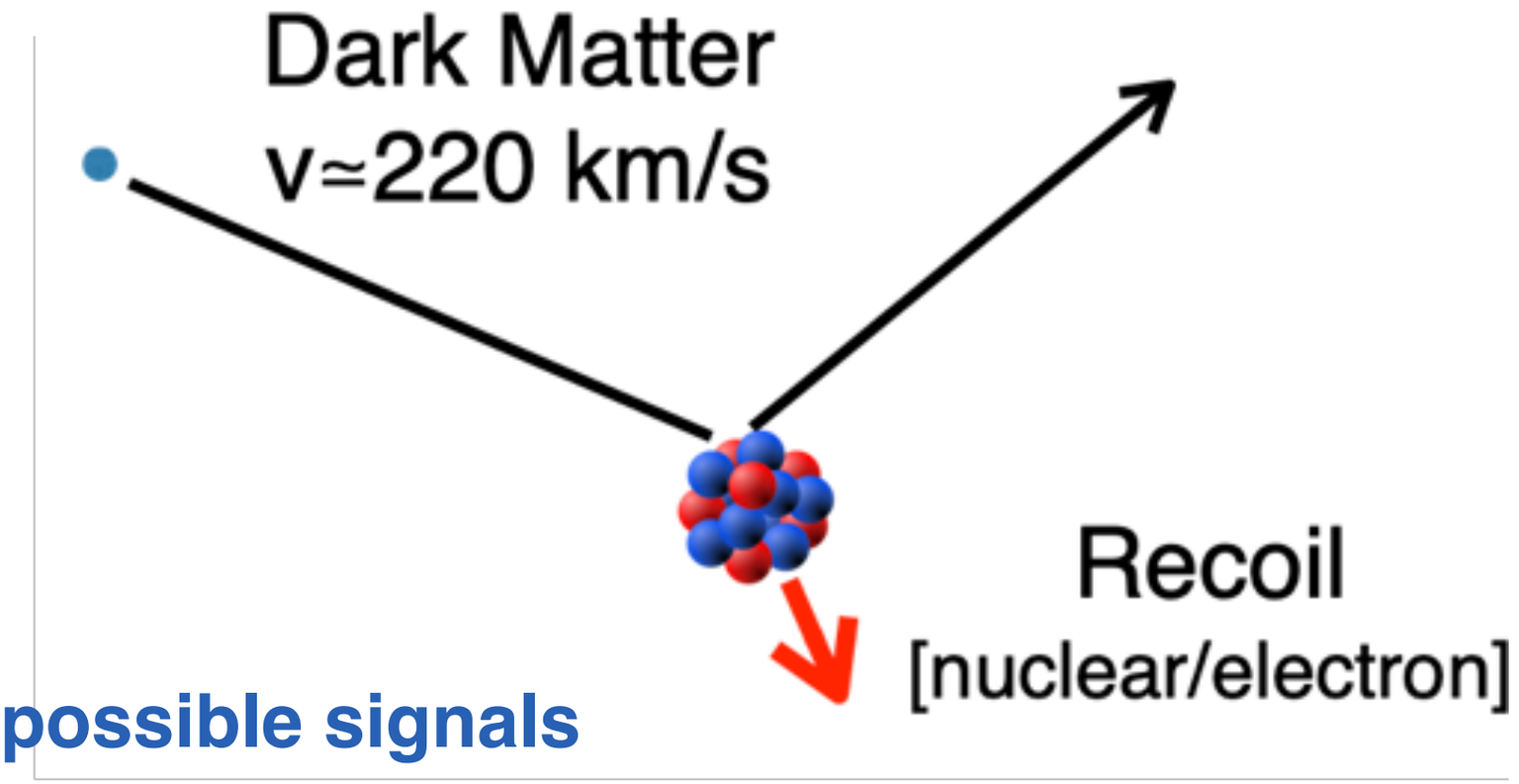
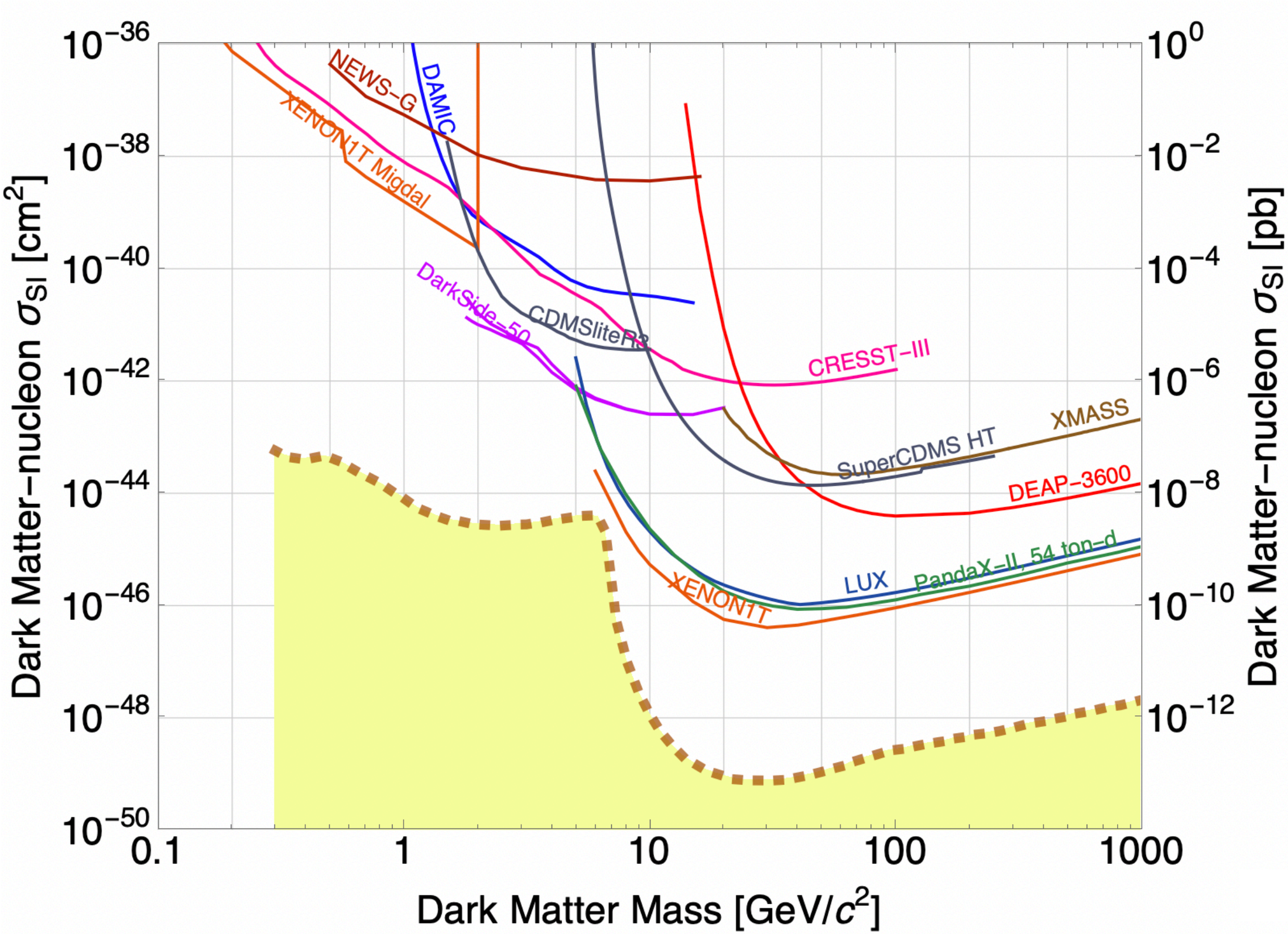




- **Many handles to confirm possible signals**
  - Recoil energy distribution
  - Seasonal variation of flux
  - Directional detection

Direct Detection: Landscape



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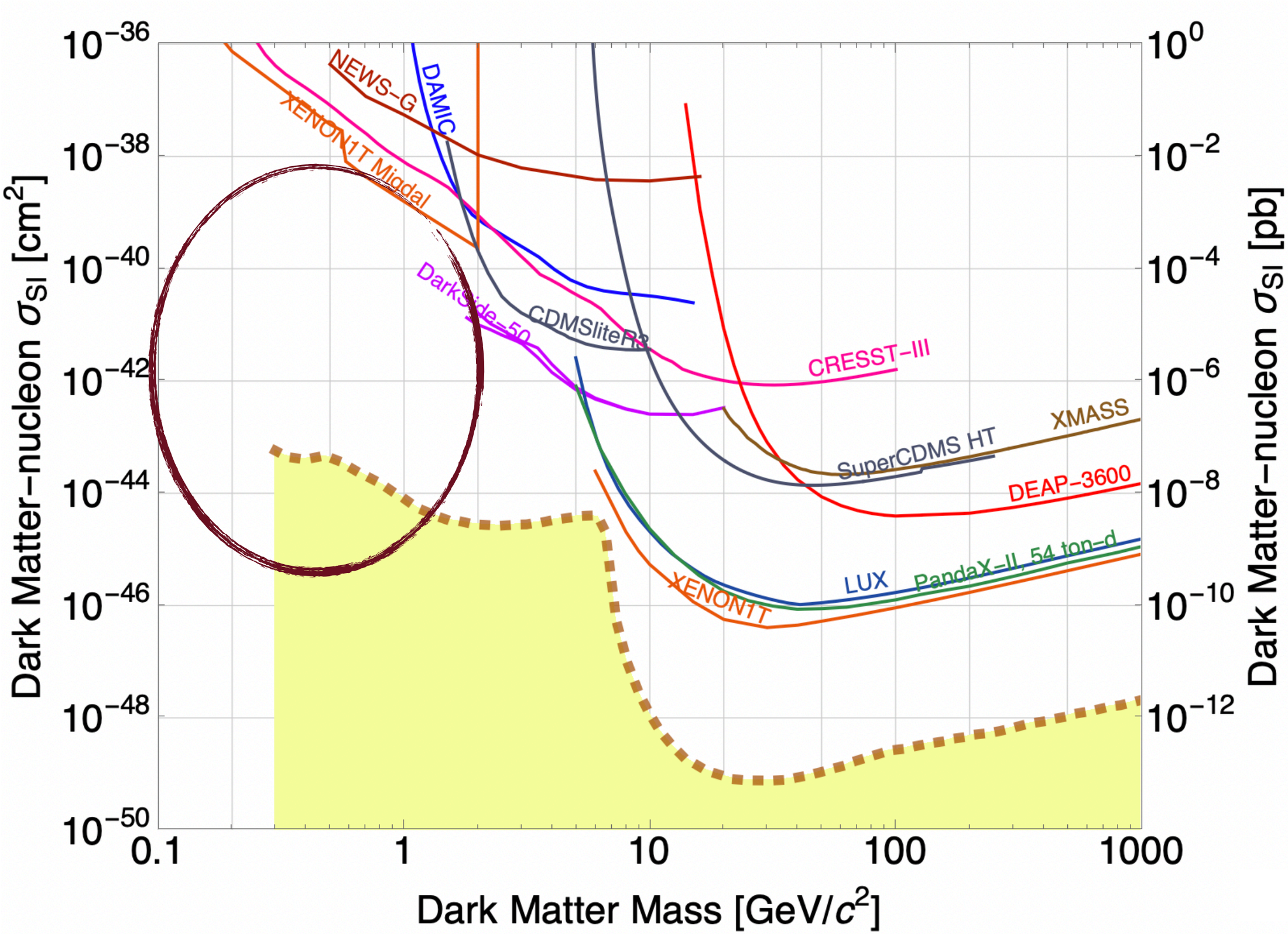

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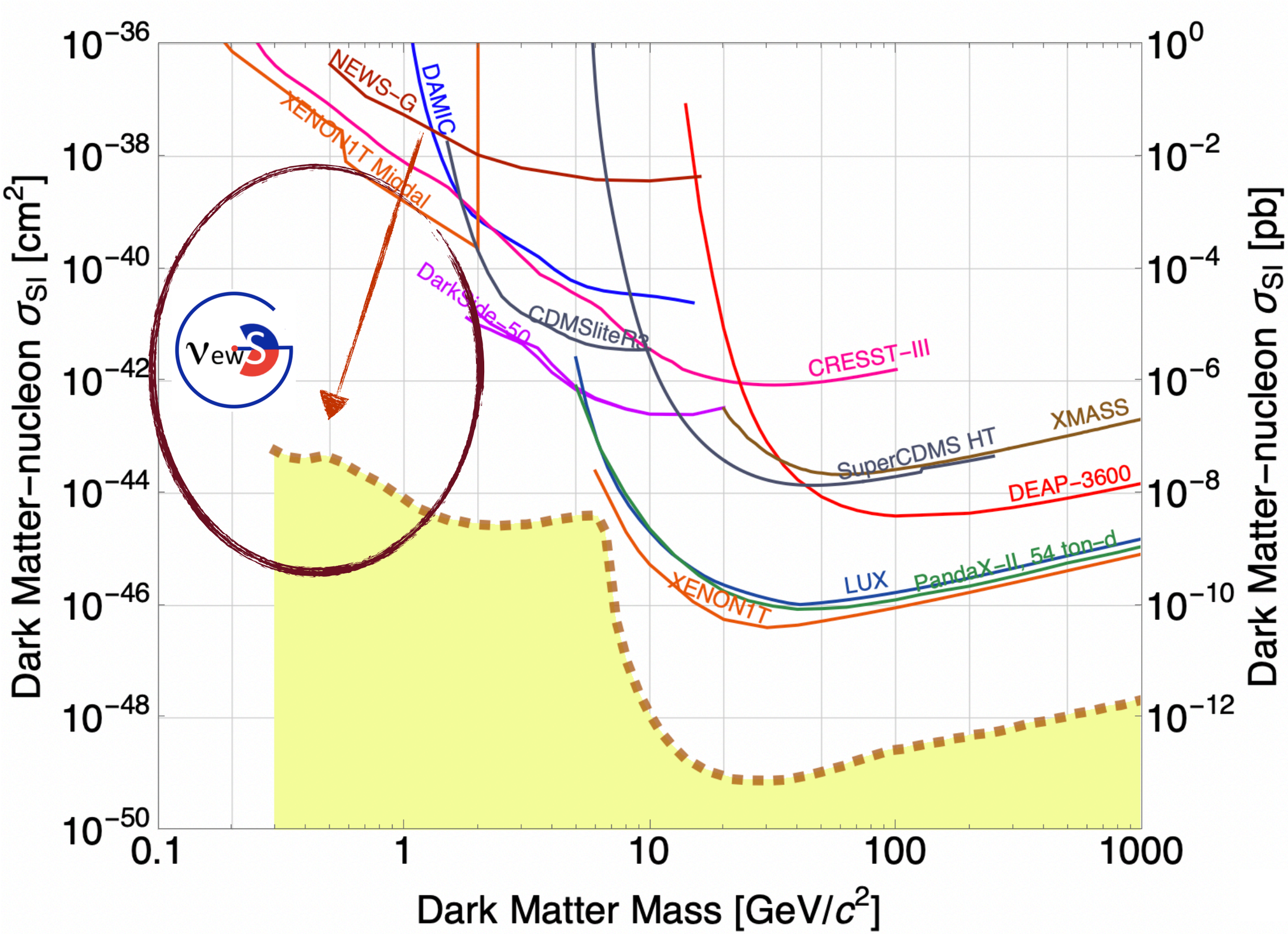


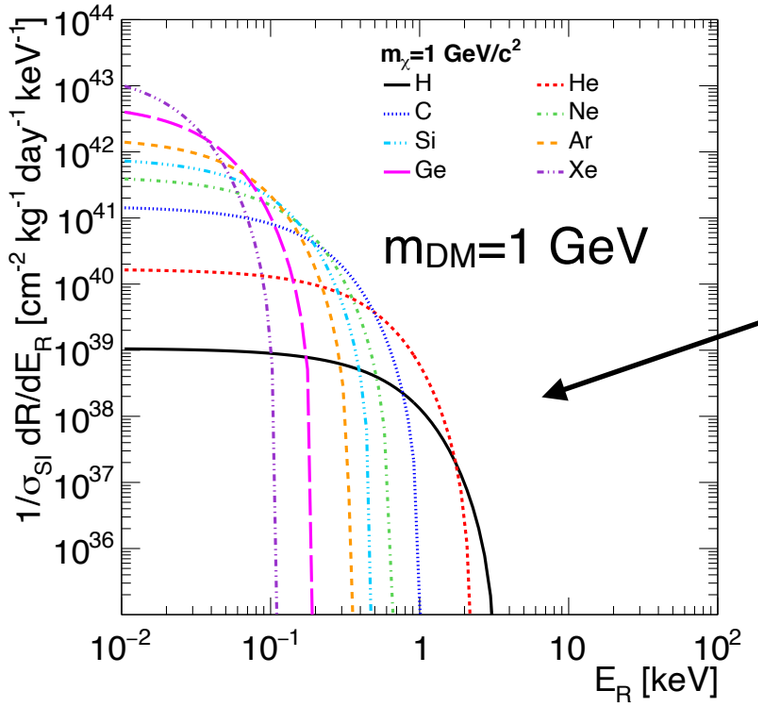
New Experiment With Spheres - Gas

9th collaboration meeting, December 2020

- NEWS-G Collaboration
  - 5 countries
  - 10 institutes
  - ~40 collaborators
- Three underground laboratories
  - SNOLAB
  - Laboratoire Souterrain de Modane
  - Boulby Underground Laboratory

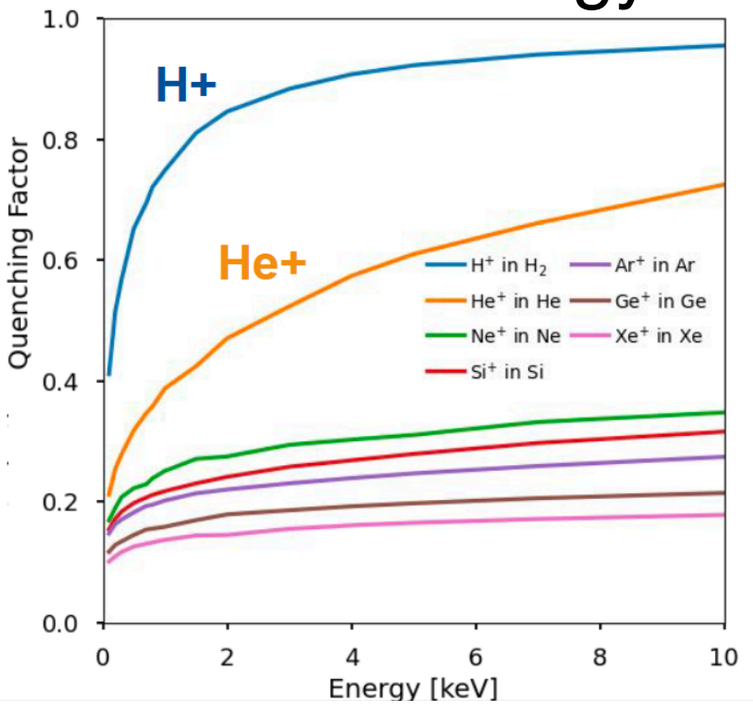
Direct Detection: Light Dark Matter

Favourable recoil energy distribution for lighter targets



Recoil Energy Distribution

For lighter elements more of the recoil energy turns into detectable signal

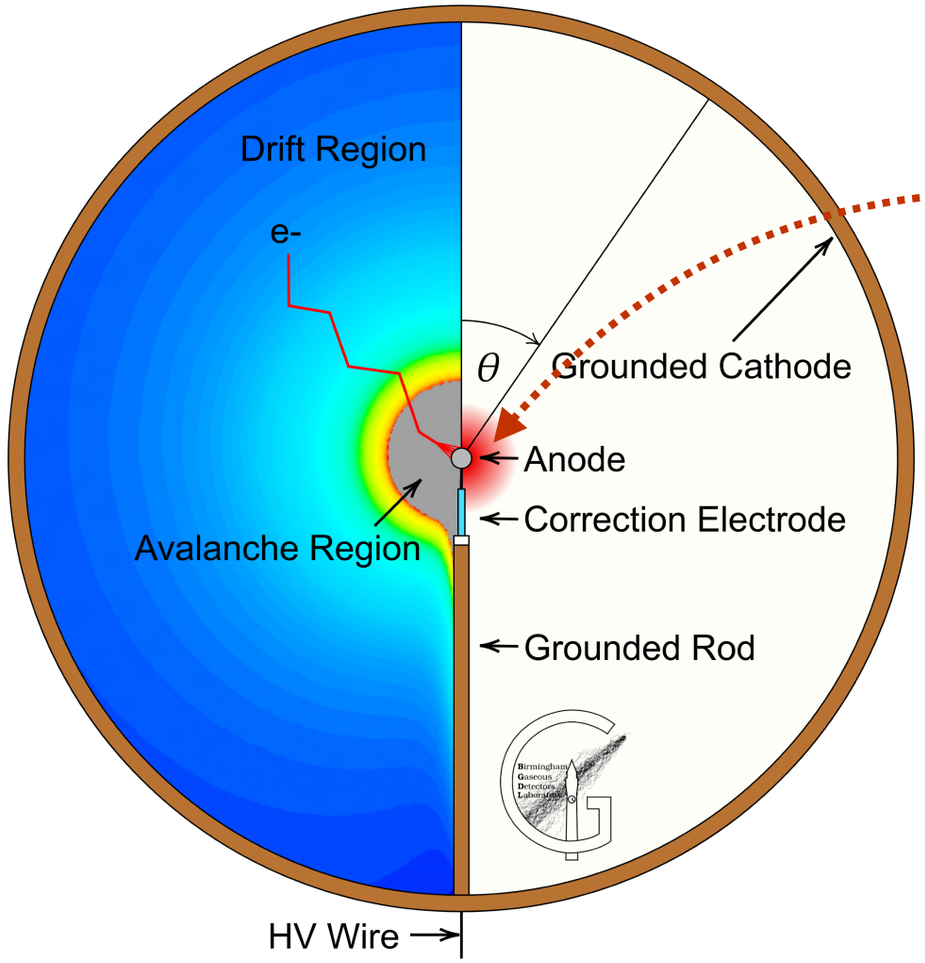


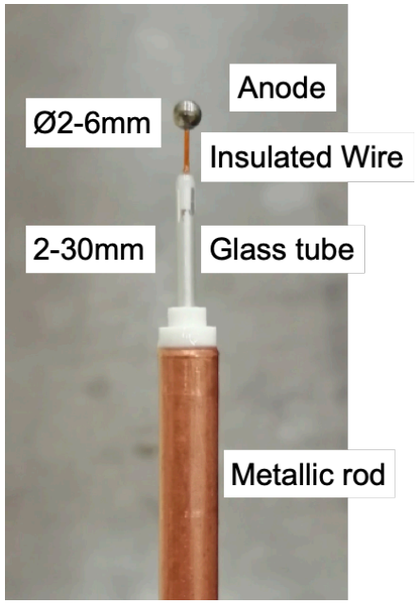
See talks by Marie Vidal and Jean-Francois Caron

Spherical Proportional Counter

Electric field scales as $1/r^2$, volume divided in: "drift" and "amplification" regions

Capacitance independent of size: low electronic noise





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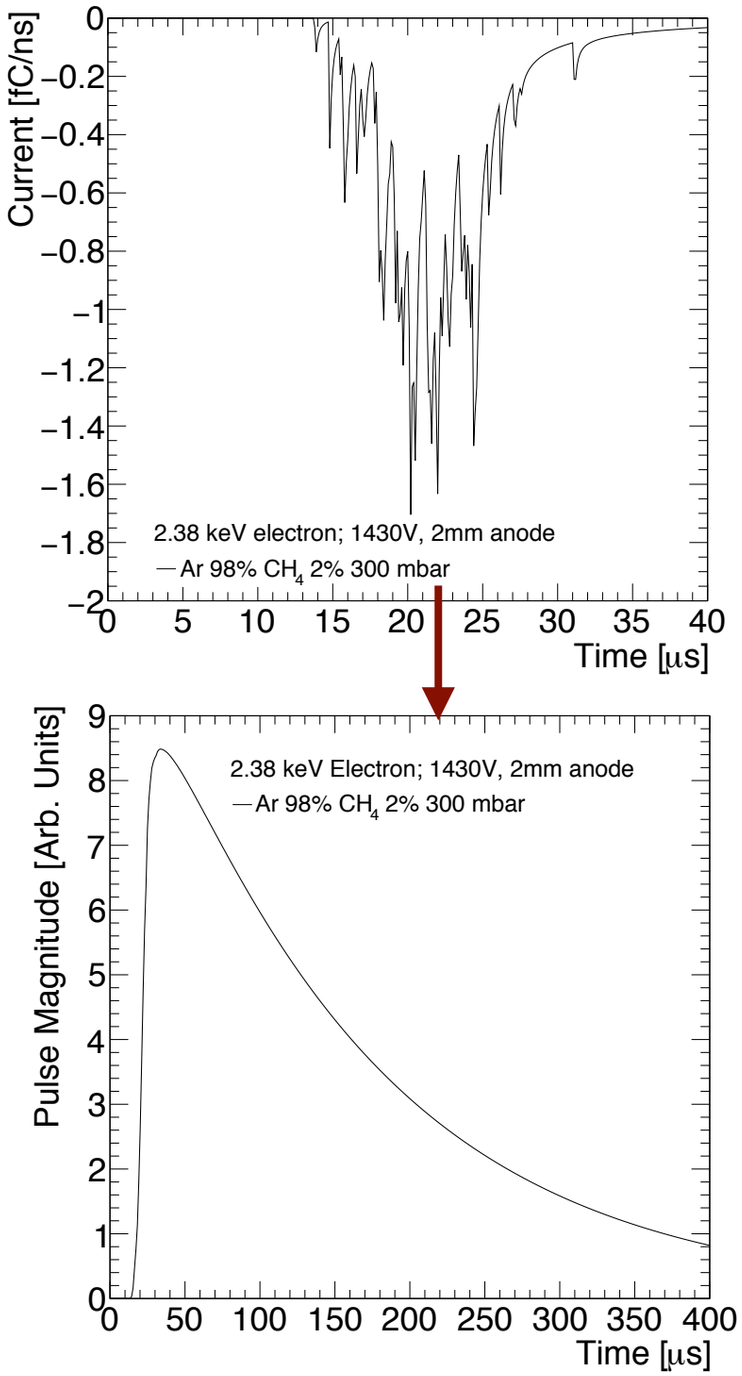

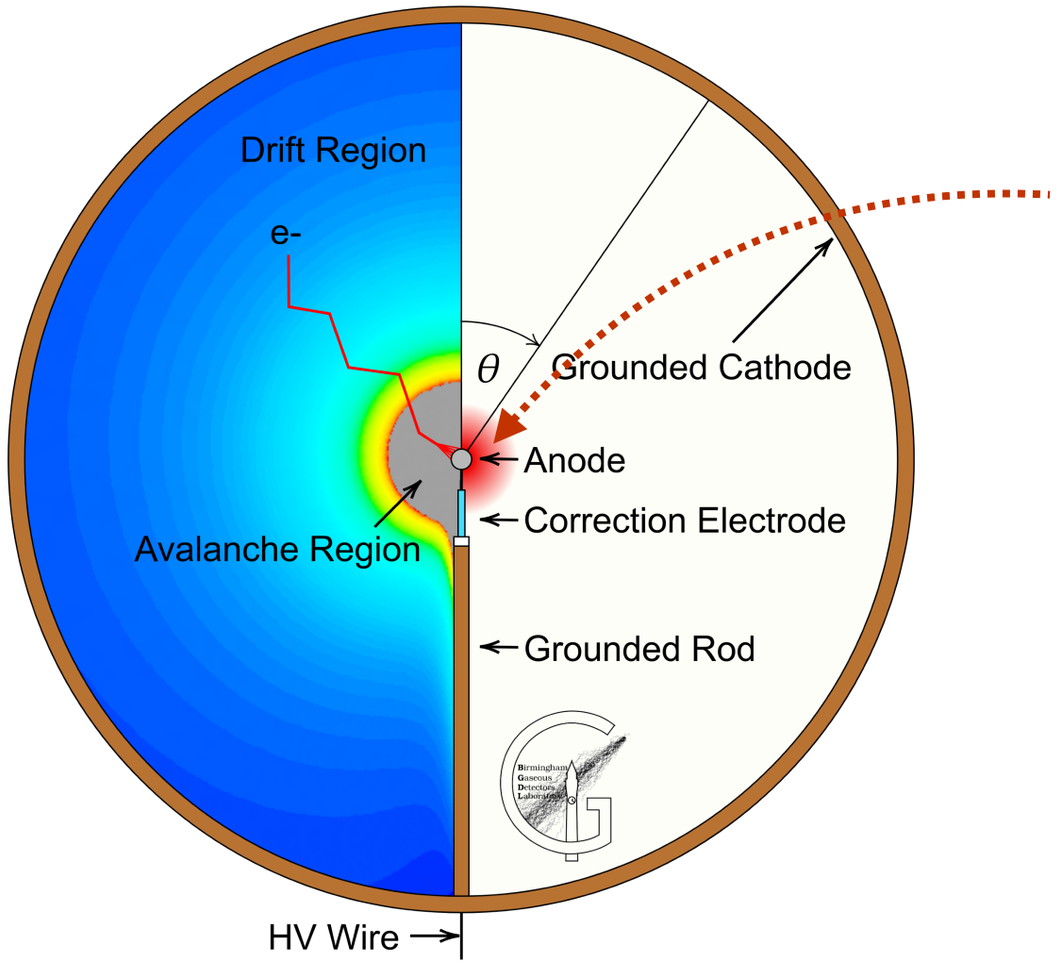

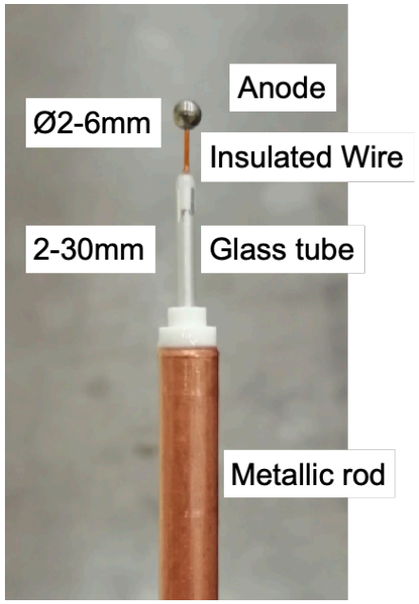

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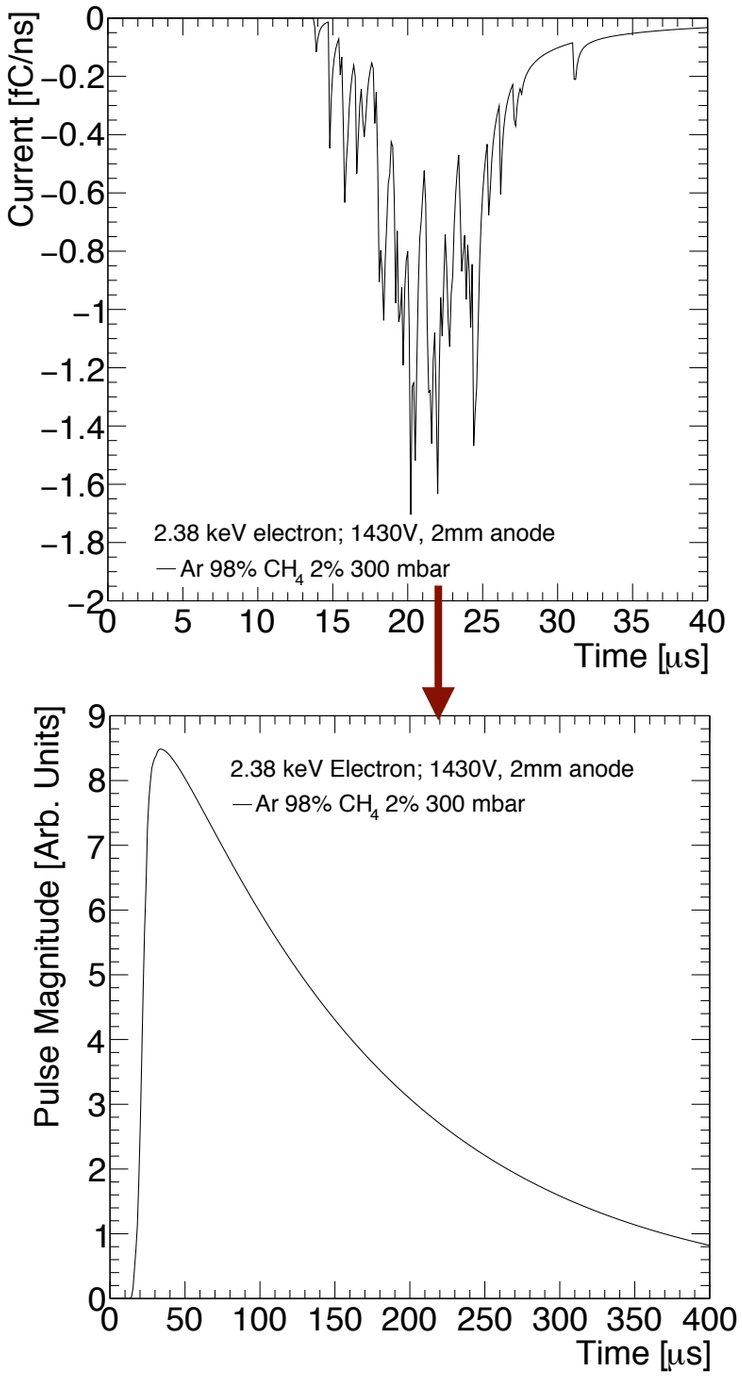
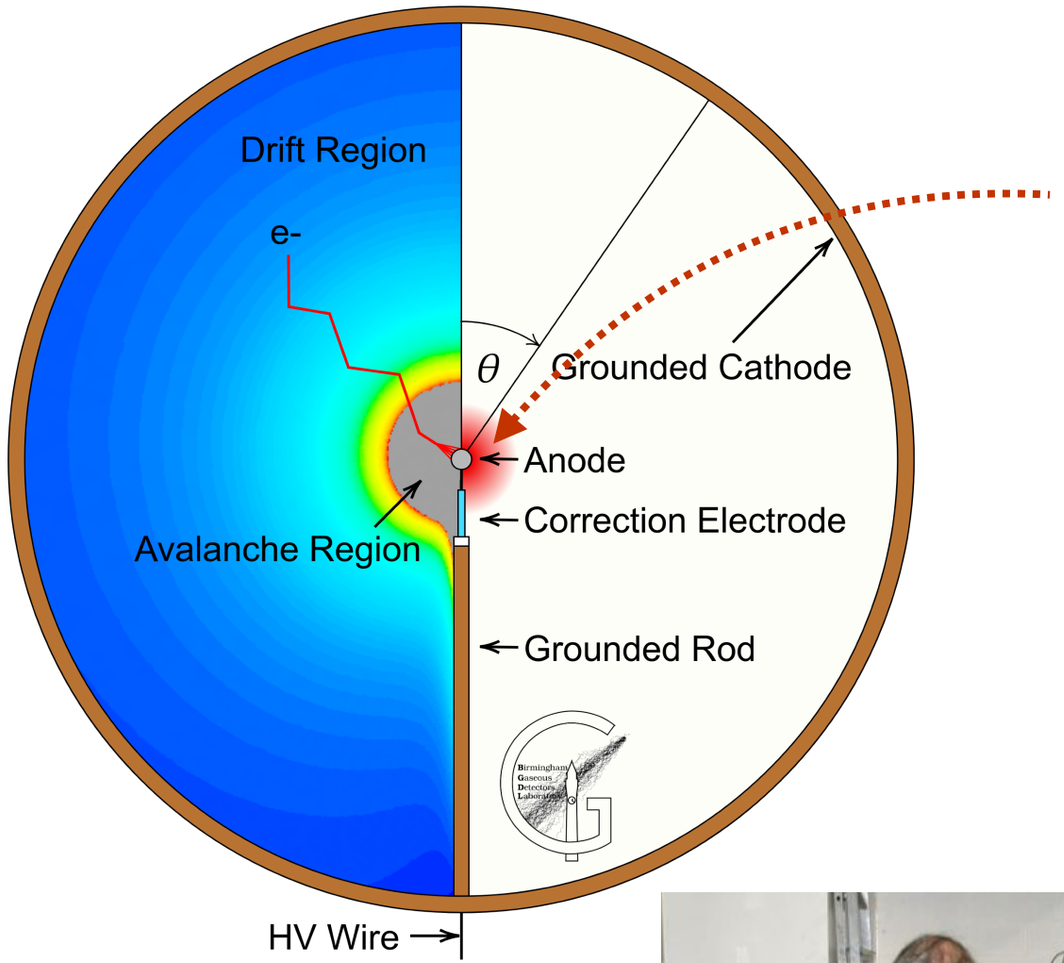
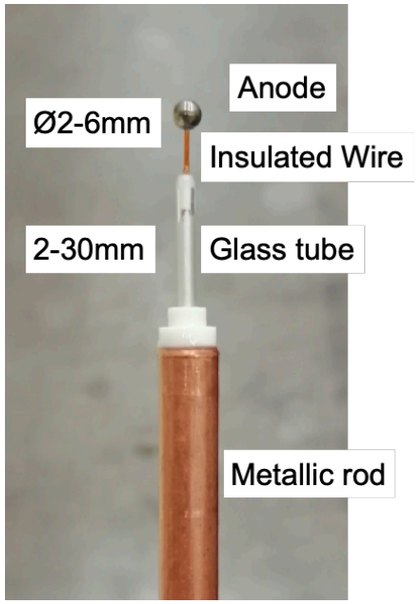
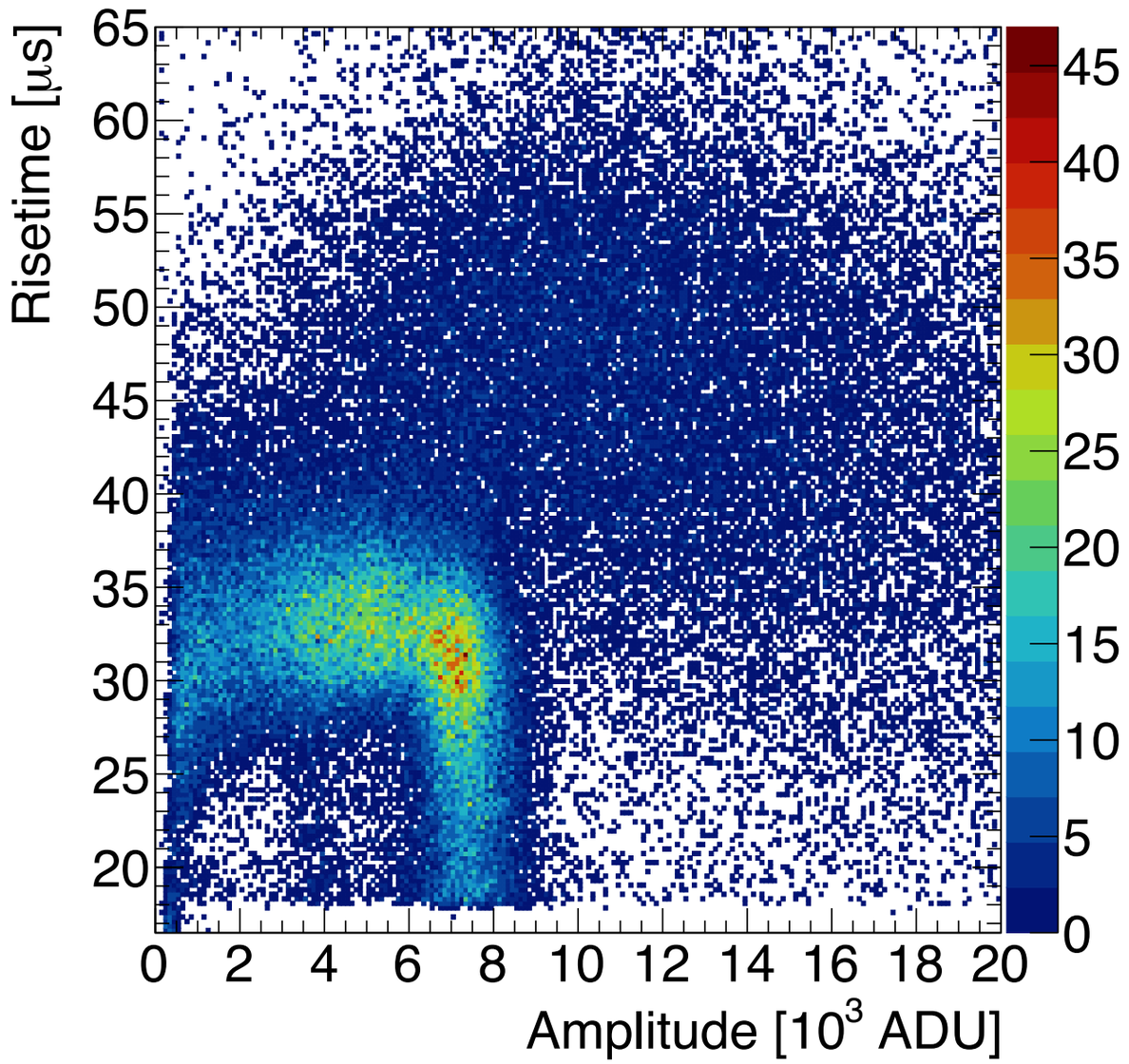






Pulse Shape Discrimination



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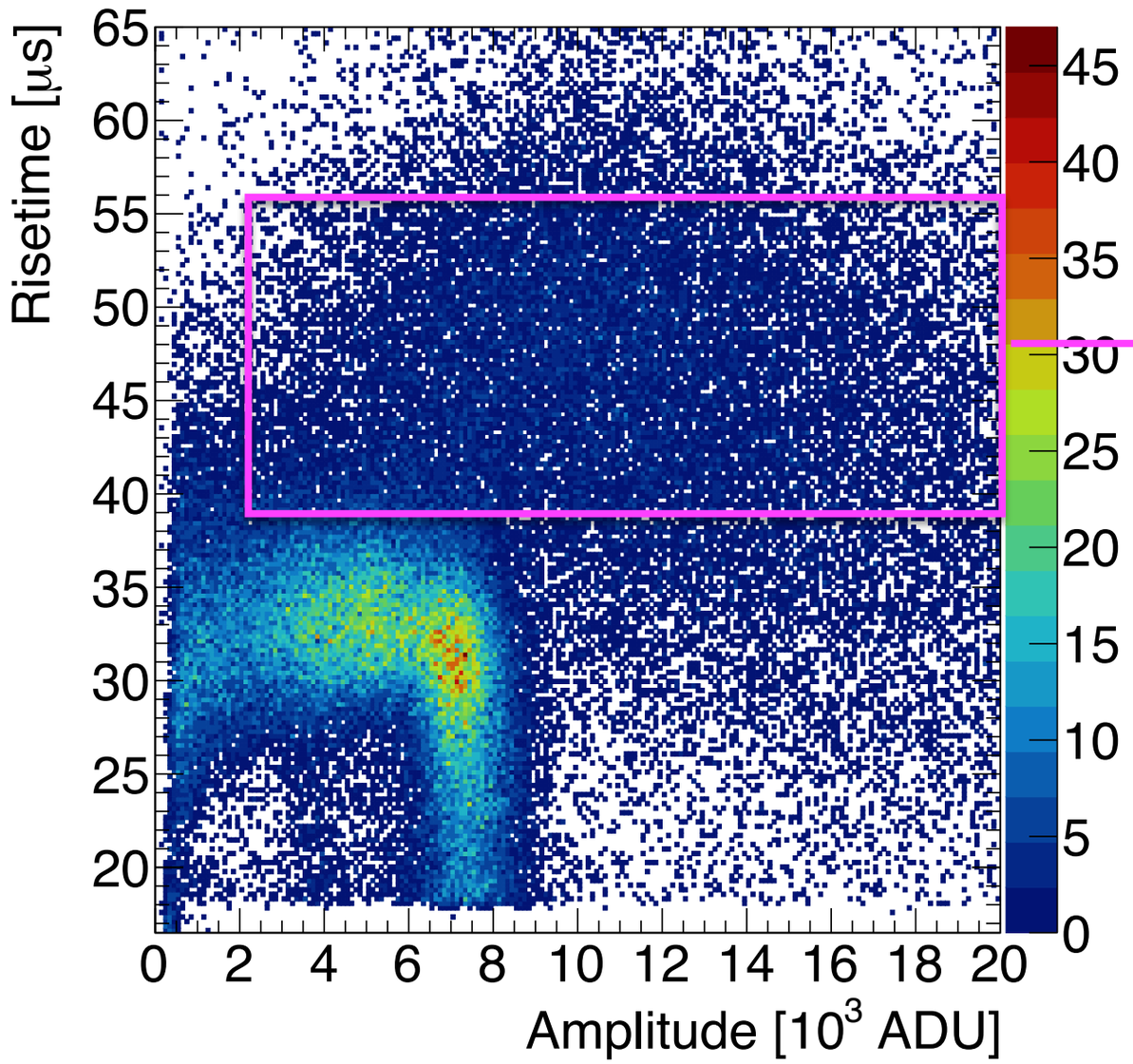
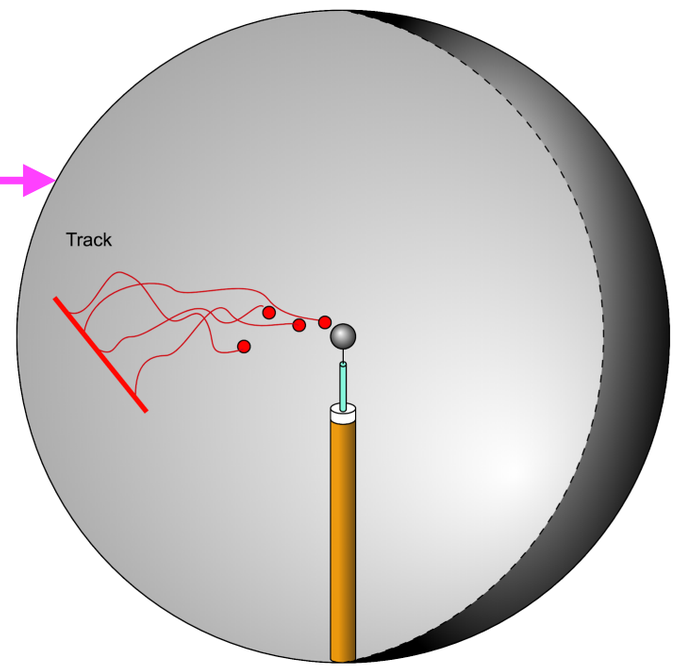
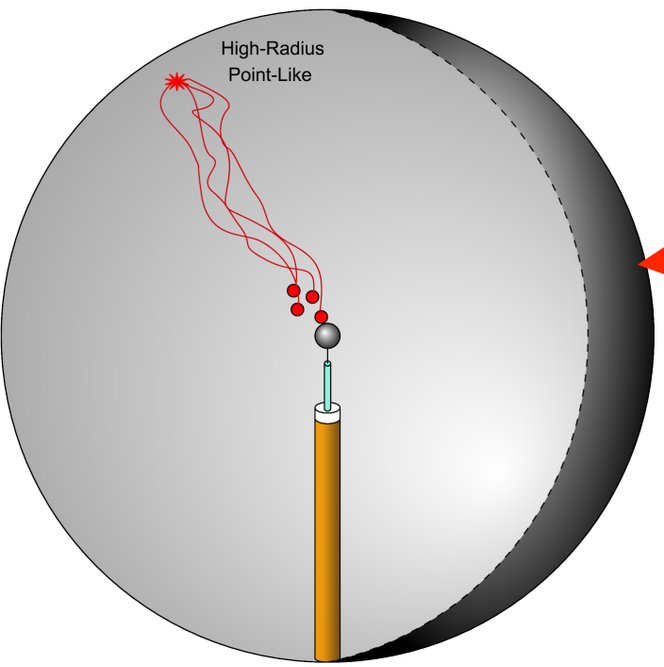


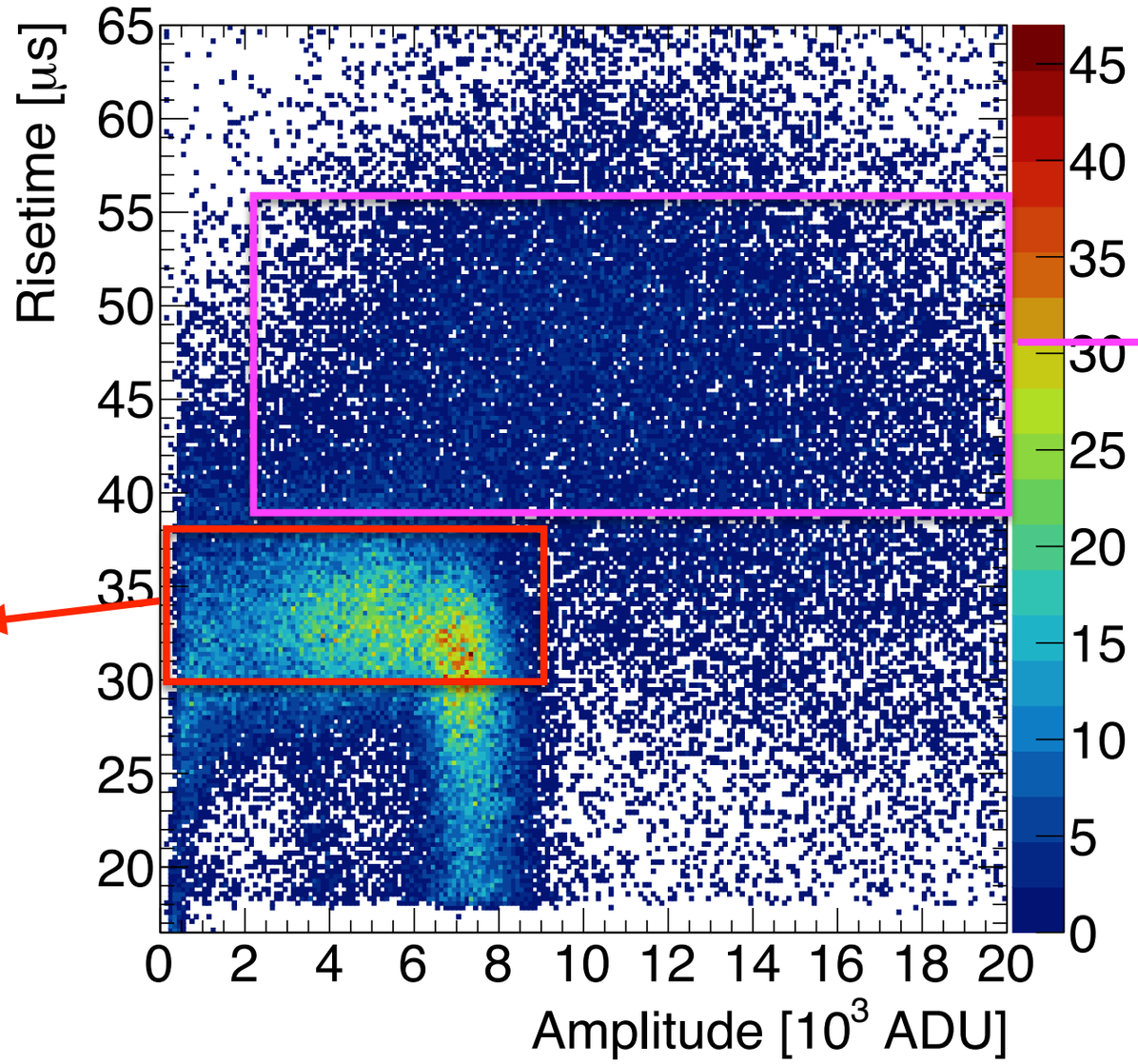


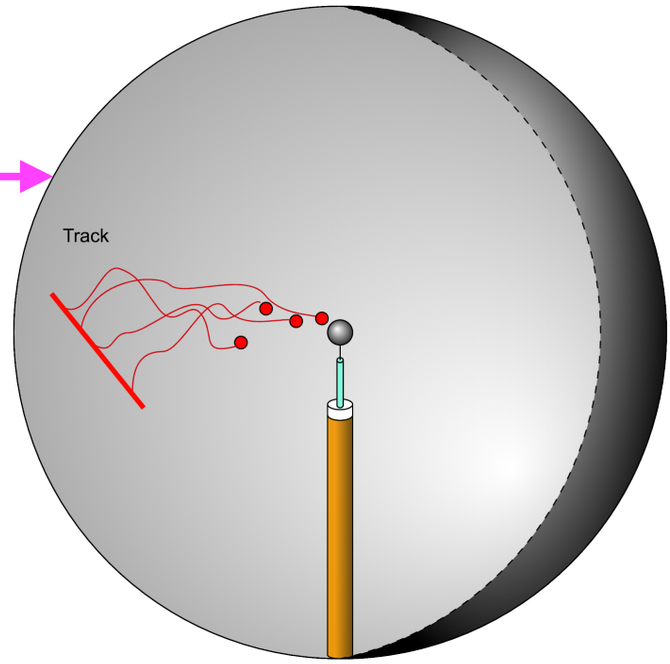
“Muon”-like events

Pulse Shape Discrimination



“Surface”-like events





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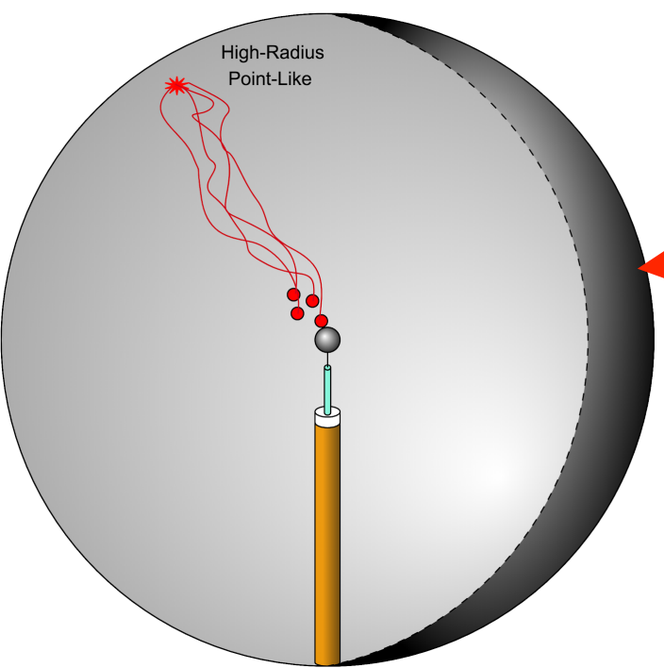

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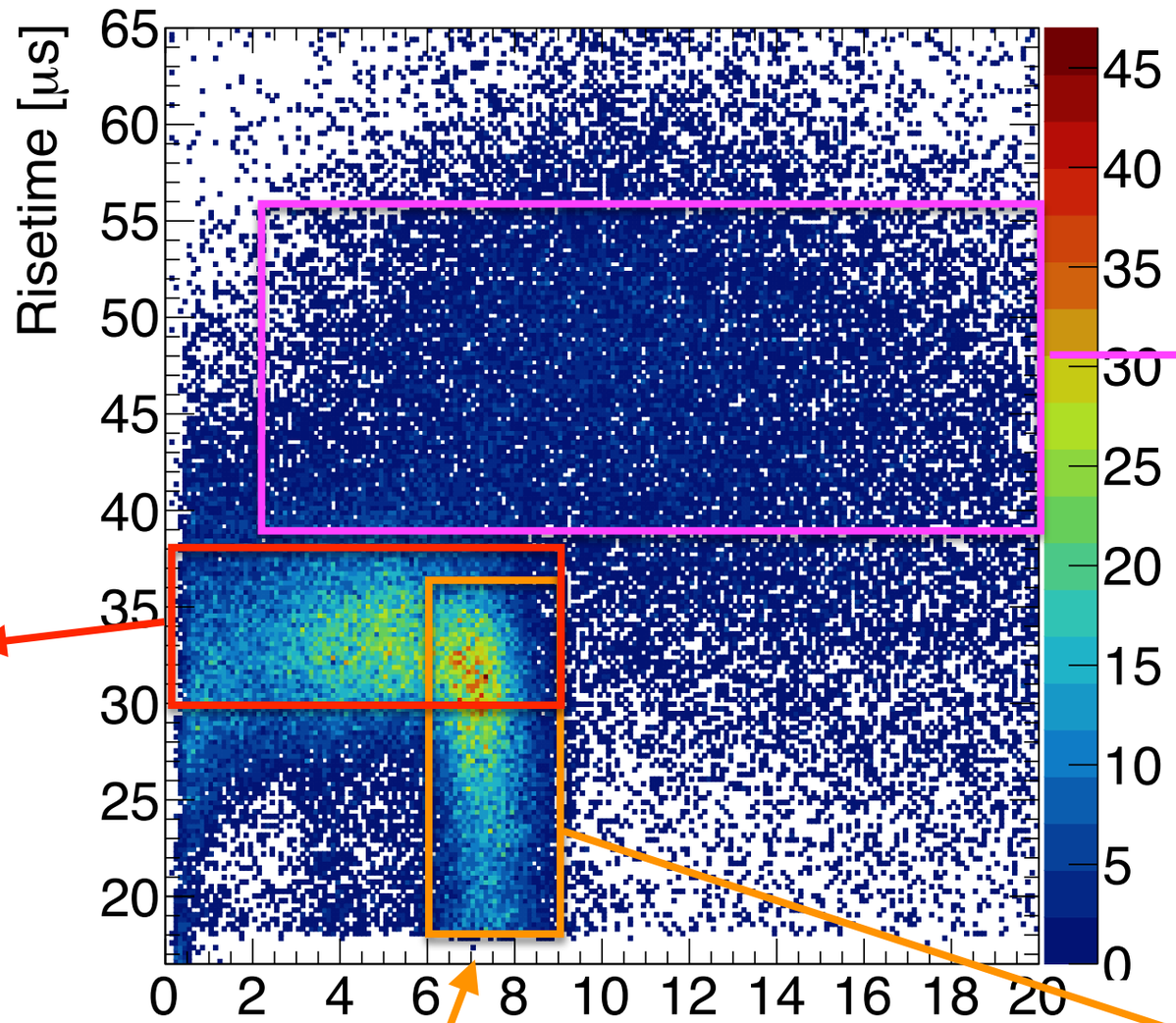
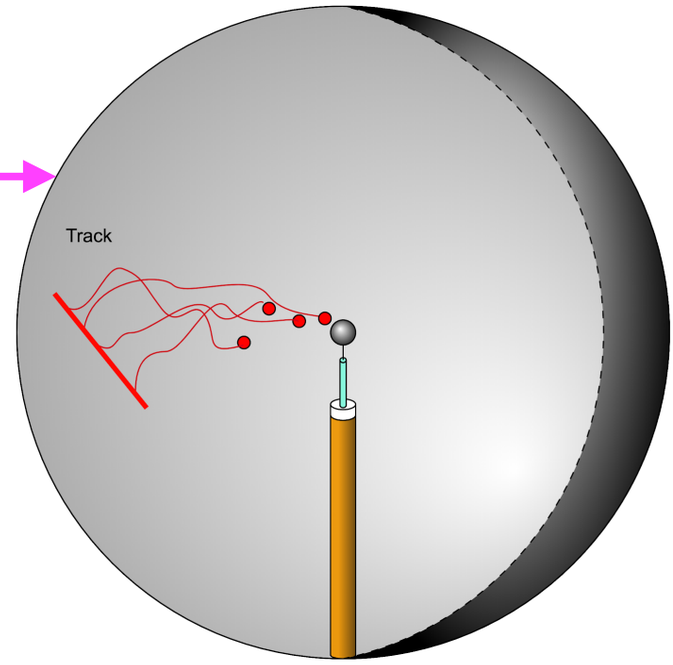


5.9 keV X-rays
from ^{55}Fe decays



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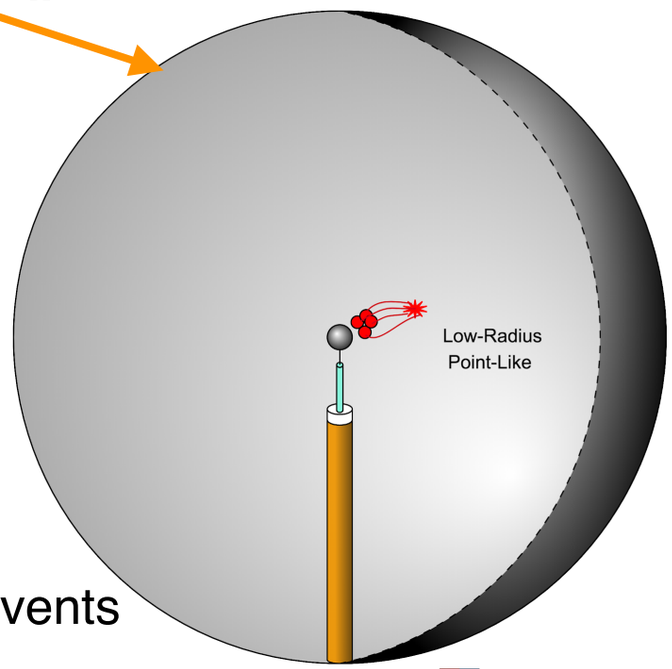
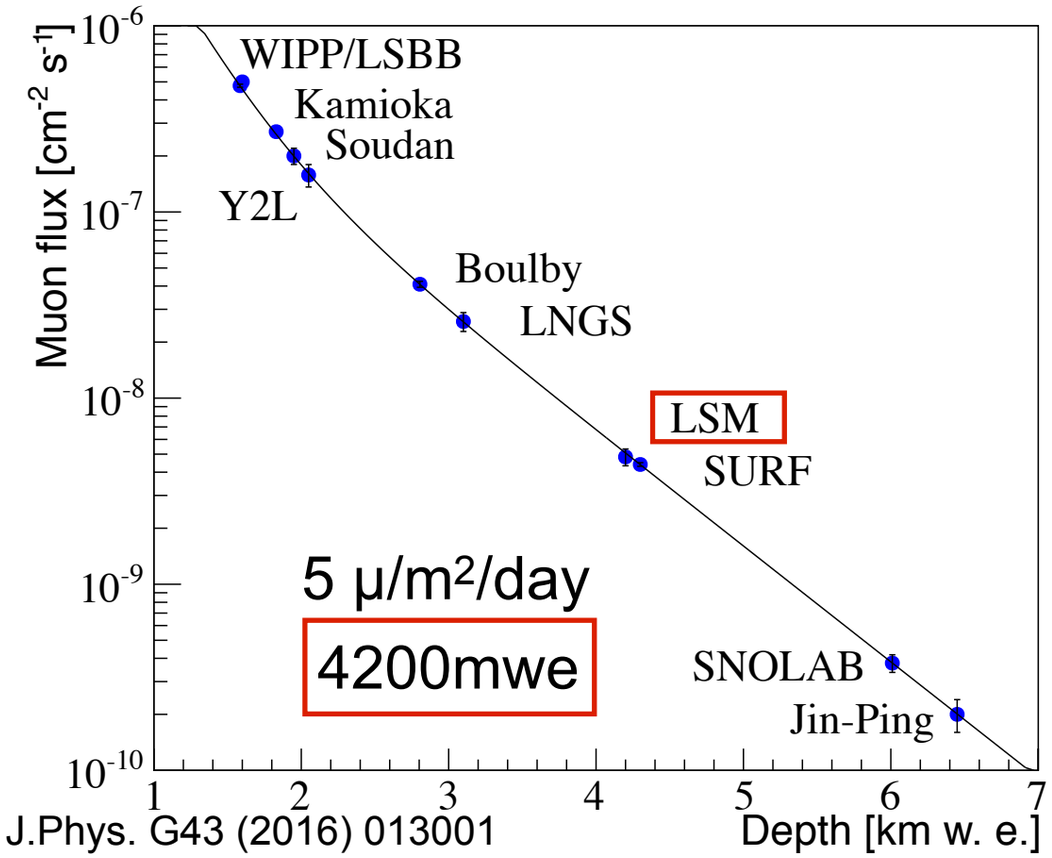
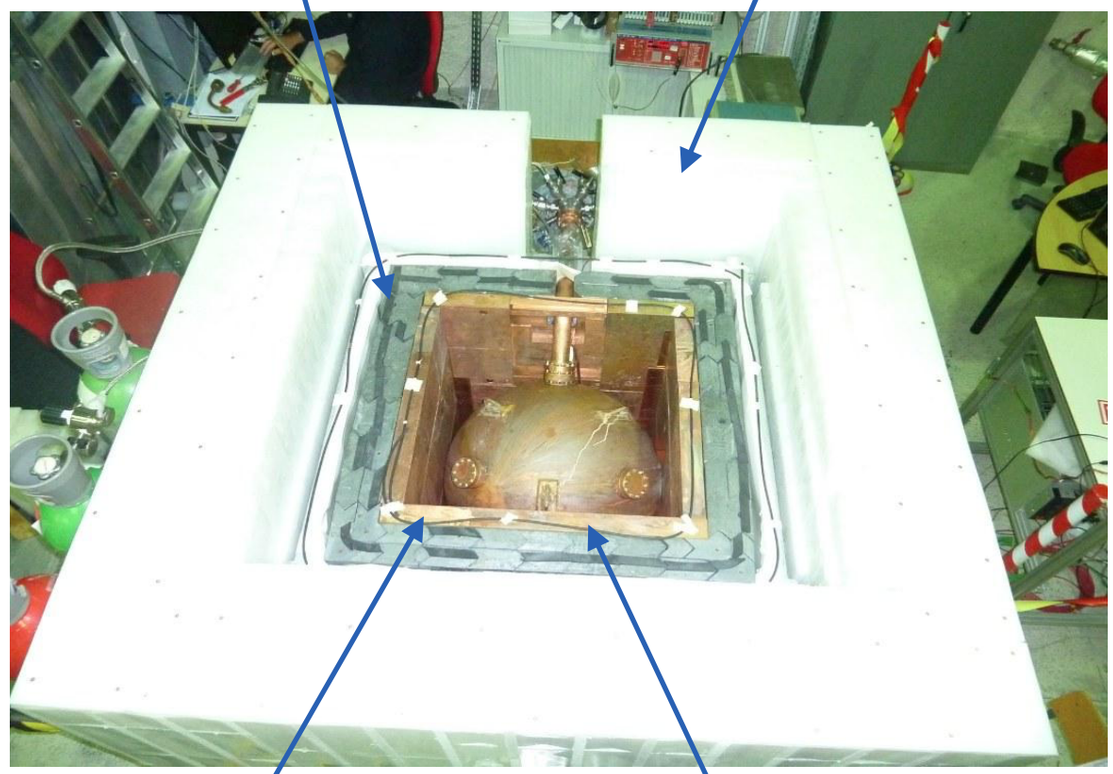
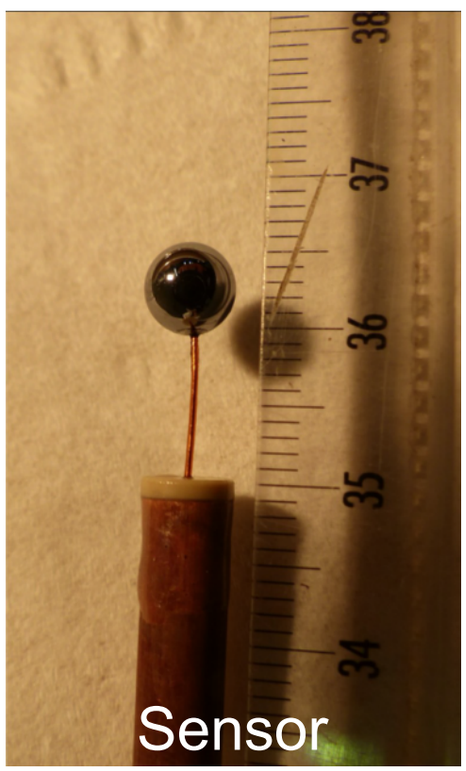


“Signal”-like events

NEWS-G: Prototype at Modane



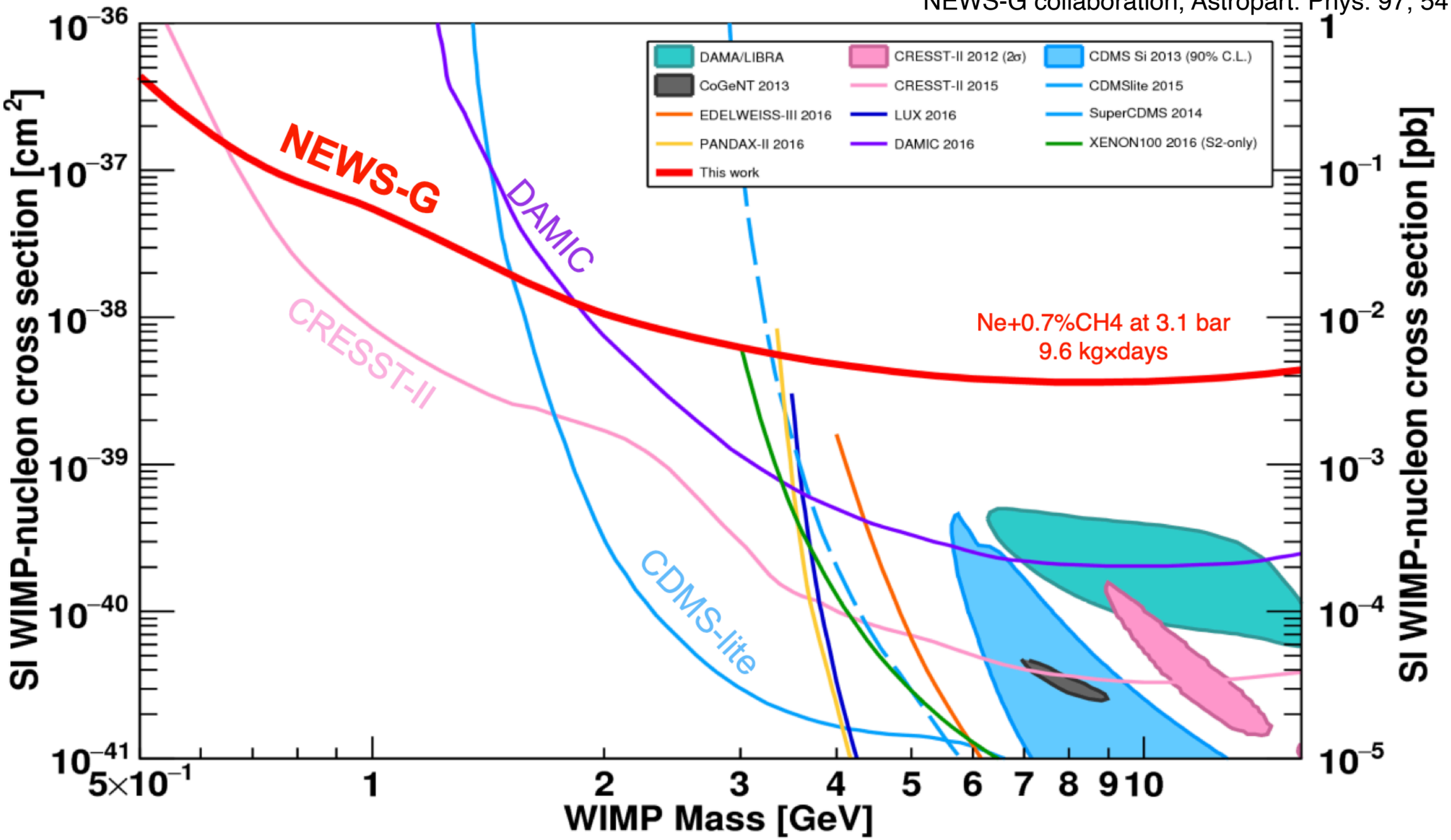




- NOSV Copper vessel (Ø60 cm)
- Equipped with a Ø6.3 mm sensor
- Chemically cleaned several times for Radon deposit removal

NEWS-G: First results

NEWS-G collaboration, Astropart. Phys. 97, 54 (2018)



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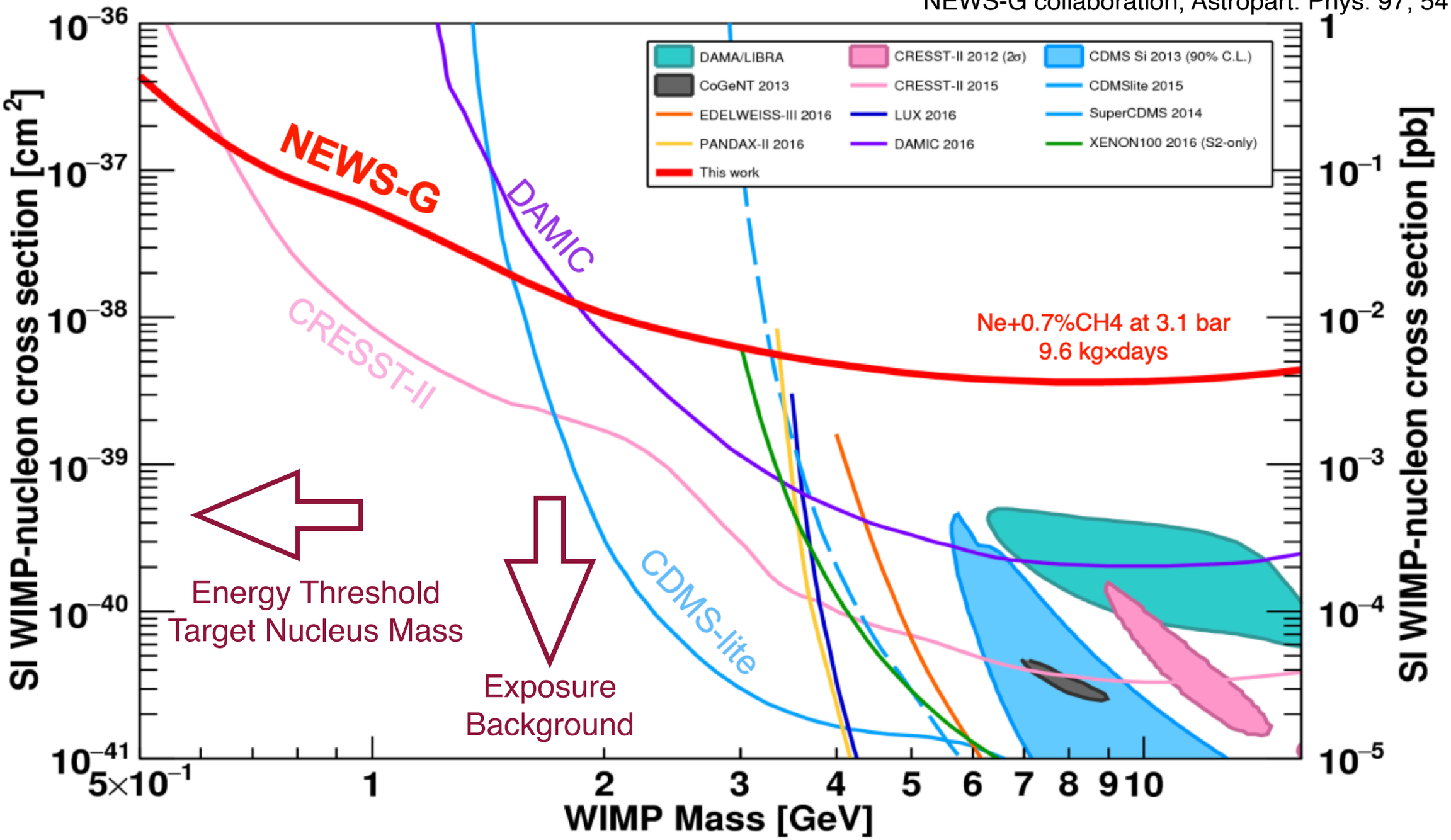
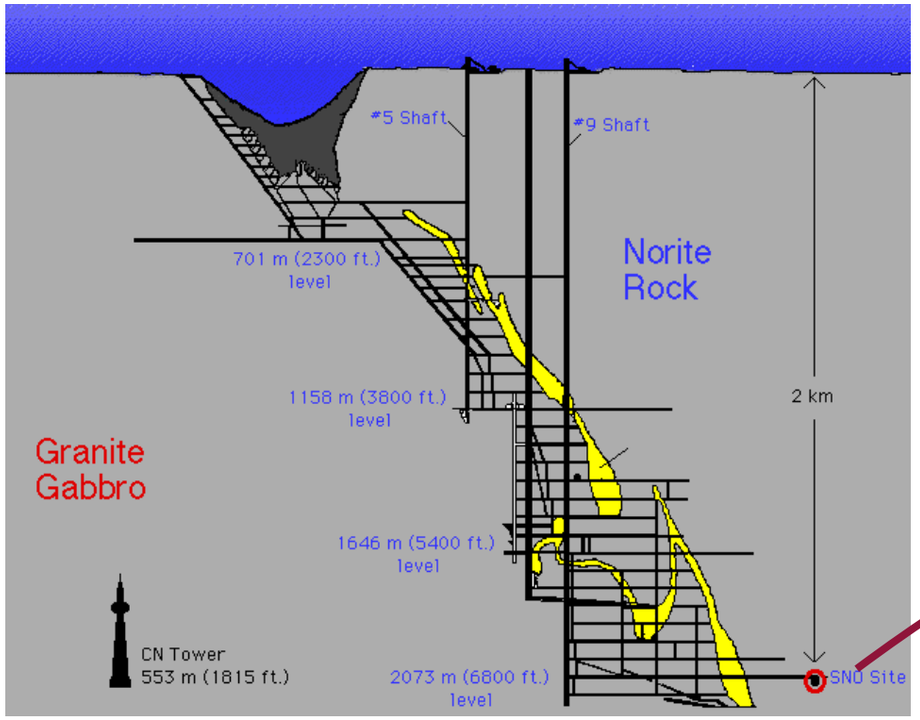
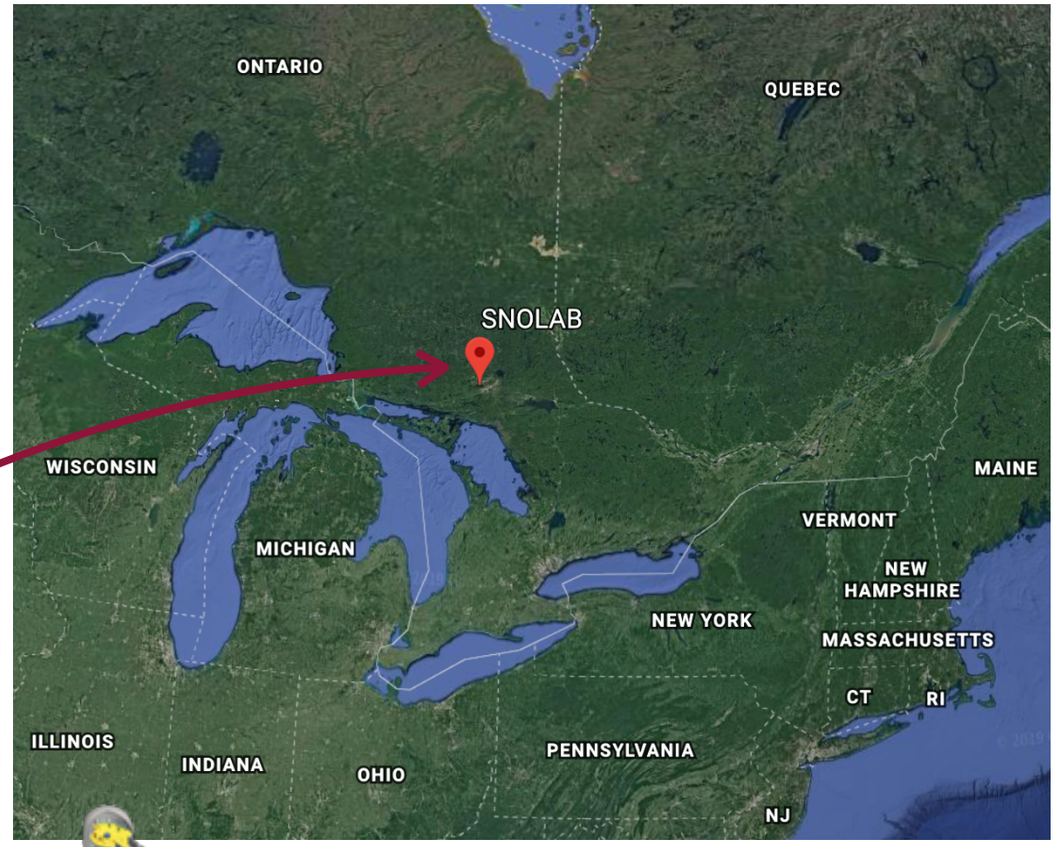


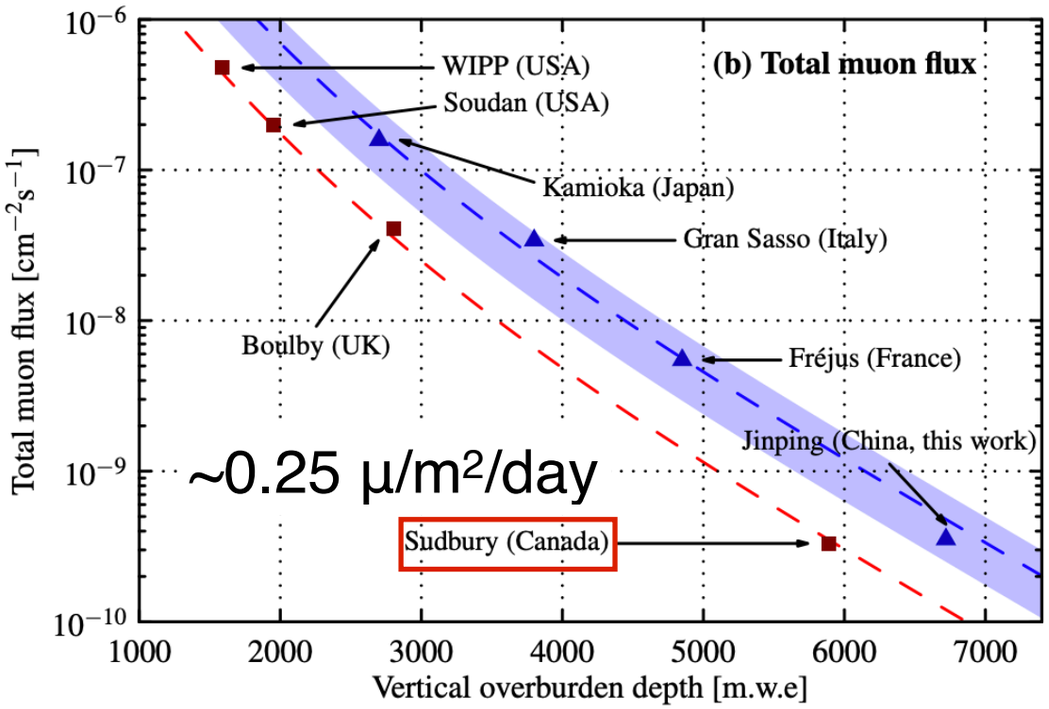
Exposure: Larger volume and higher operating pressure

Backgrounds: Higher purity materials

NEWS-G at SNOLAB







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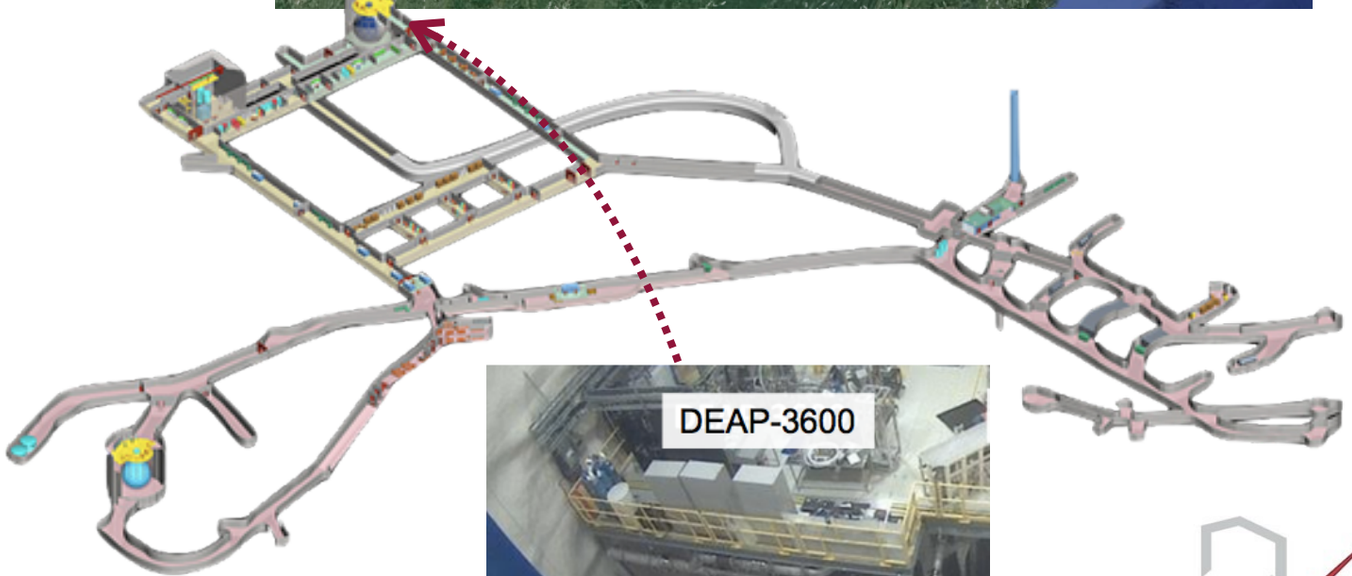

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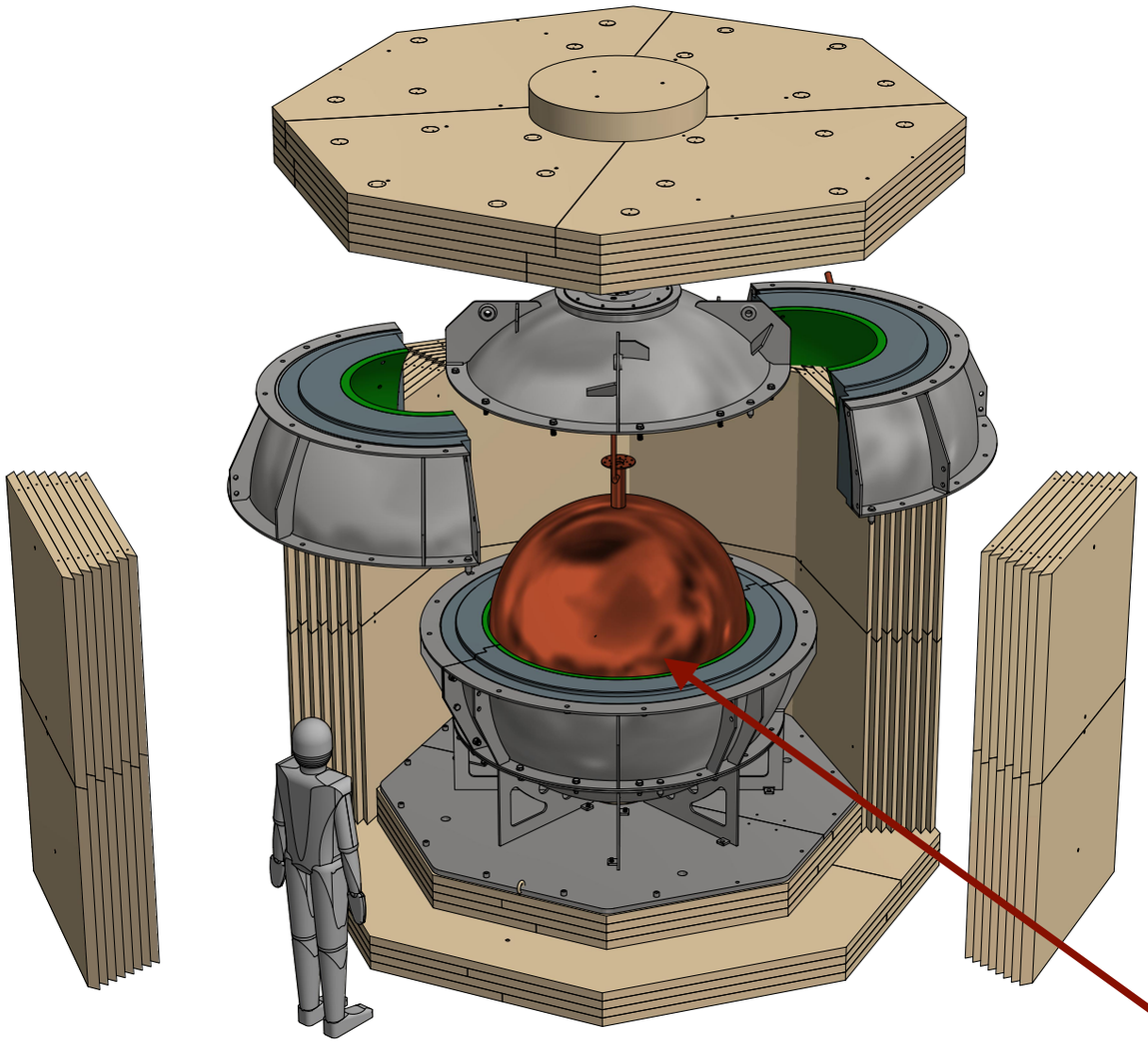
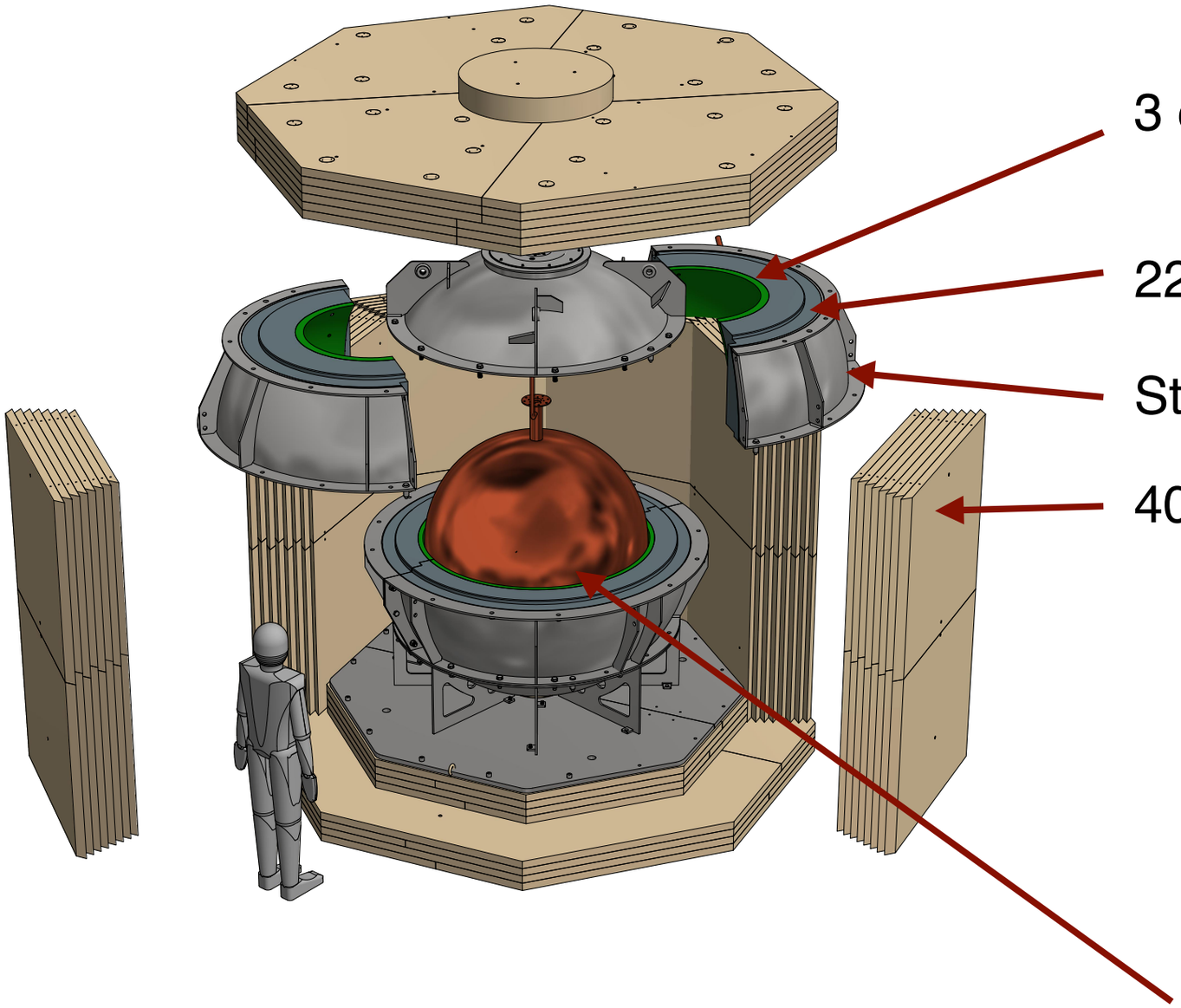


Ø140 cm
4N Copper (99.99% pure)
Assembled at LSM

NEWS-G at SNOLAB

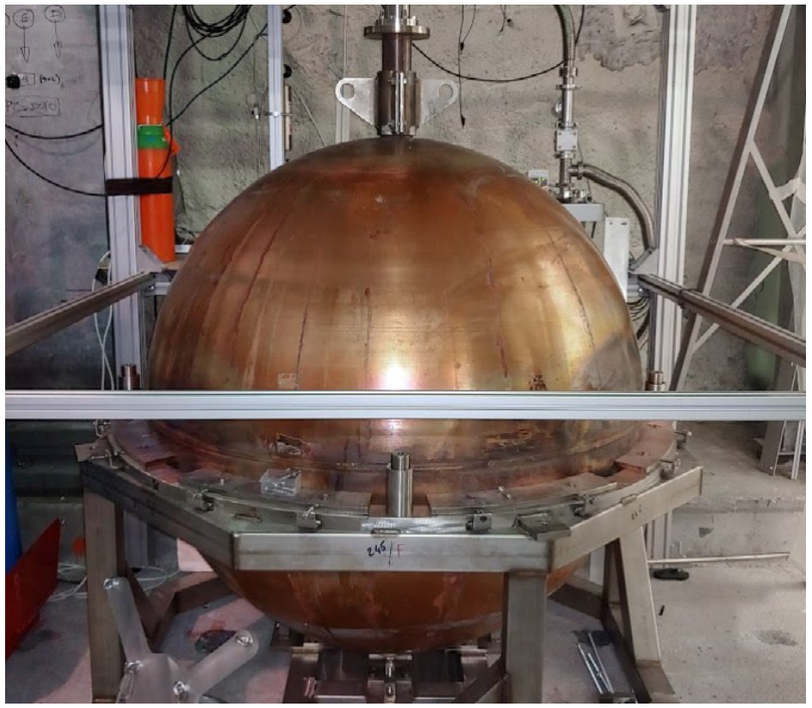


3 cm archaeological lead

22 cm of Very Low Activity lead

Stainless steel skin

40 cm high density polyethylene



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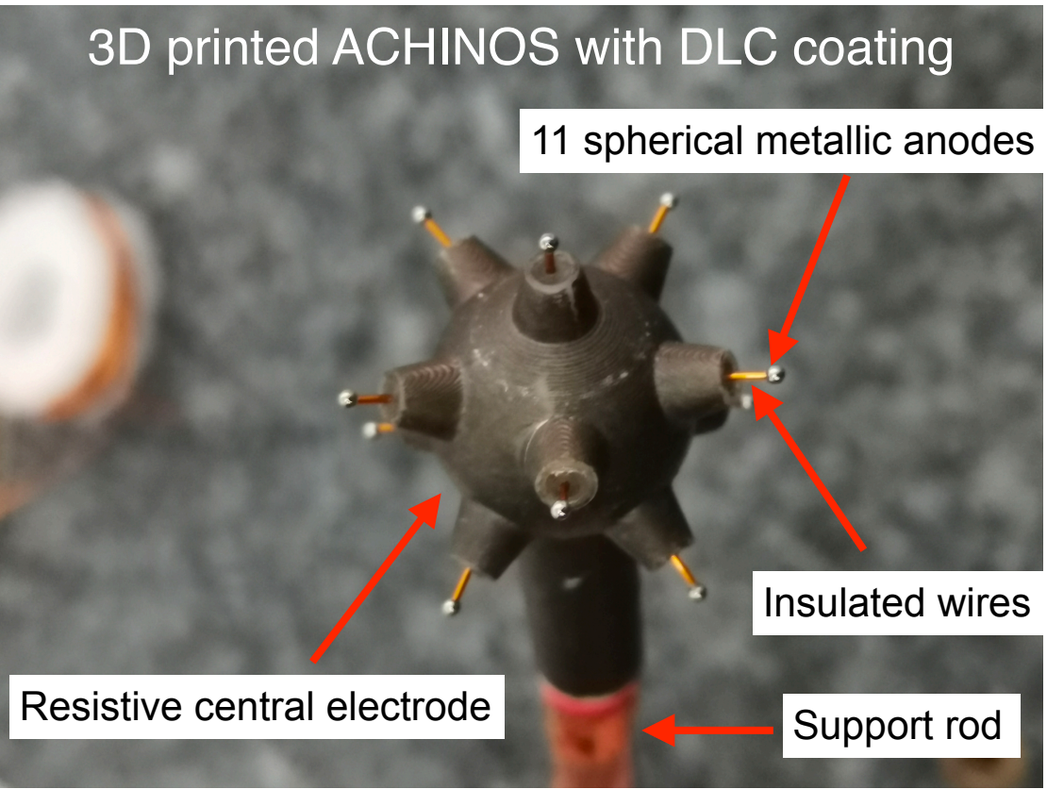
Increasing Target Mass

Instrumentation breakthrough

Single anode: Drift and Amplification fields are connected

Instrumentation breakthrough

Single anode: Drift and Amplification fields are connected

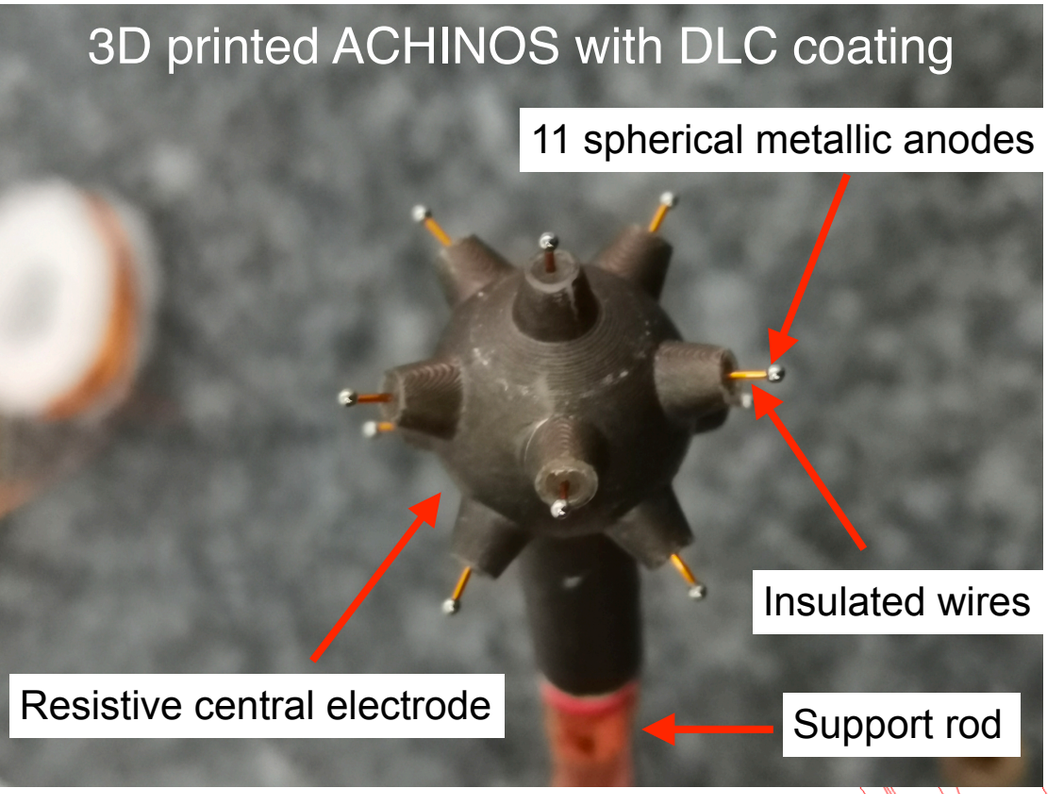


- ACHINOS: Multi-anode sensor
  - Multiple anodes placed at equal radii
  - Decoupling drift and amplification fields
  - Opportunity: individual anode read-out

Αχινός (greek. sea urchin)

Instrumentation breakthrough

Single anode: Drift and Amplification fields are connected



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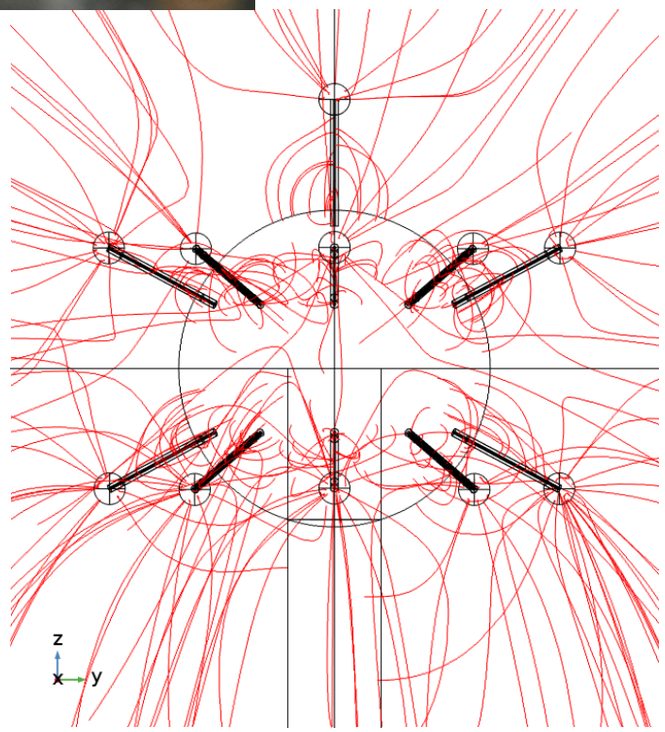
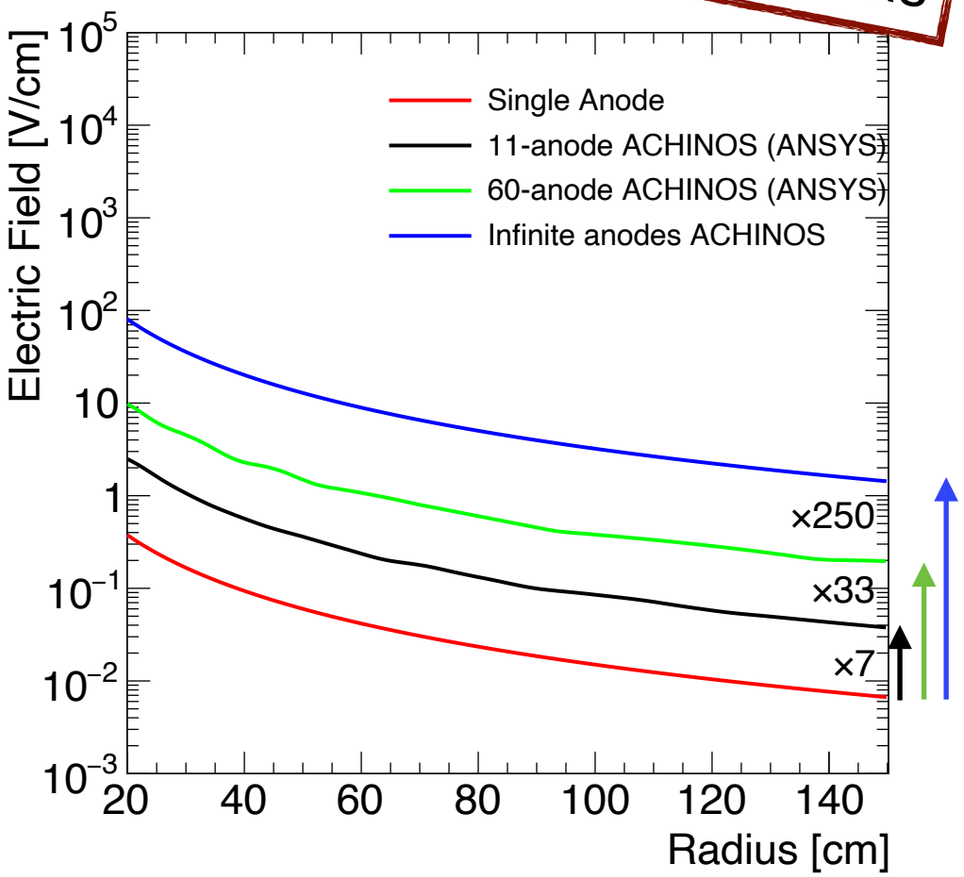


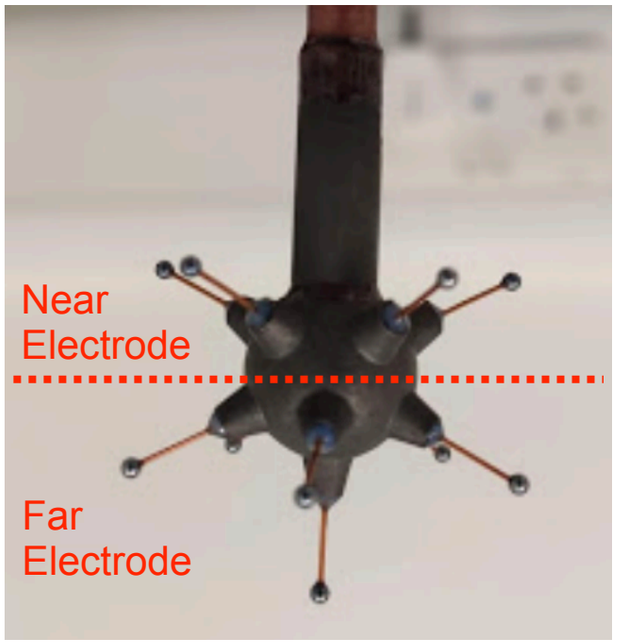
See talk by Ioannis Katsioulas

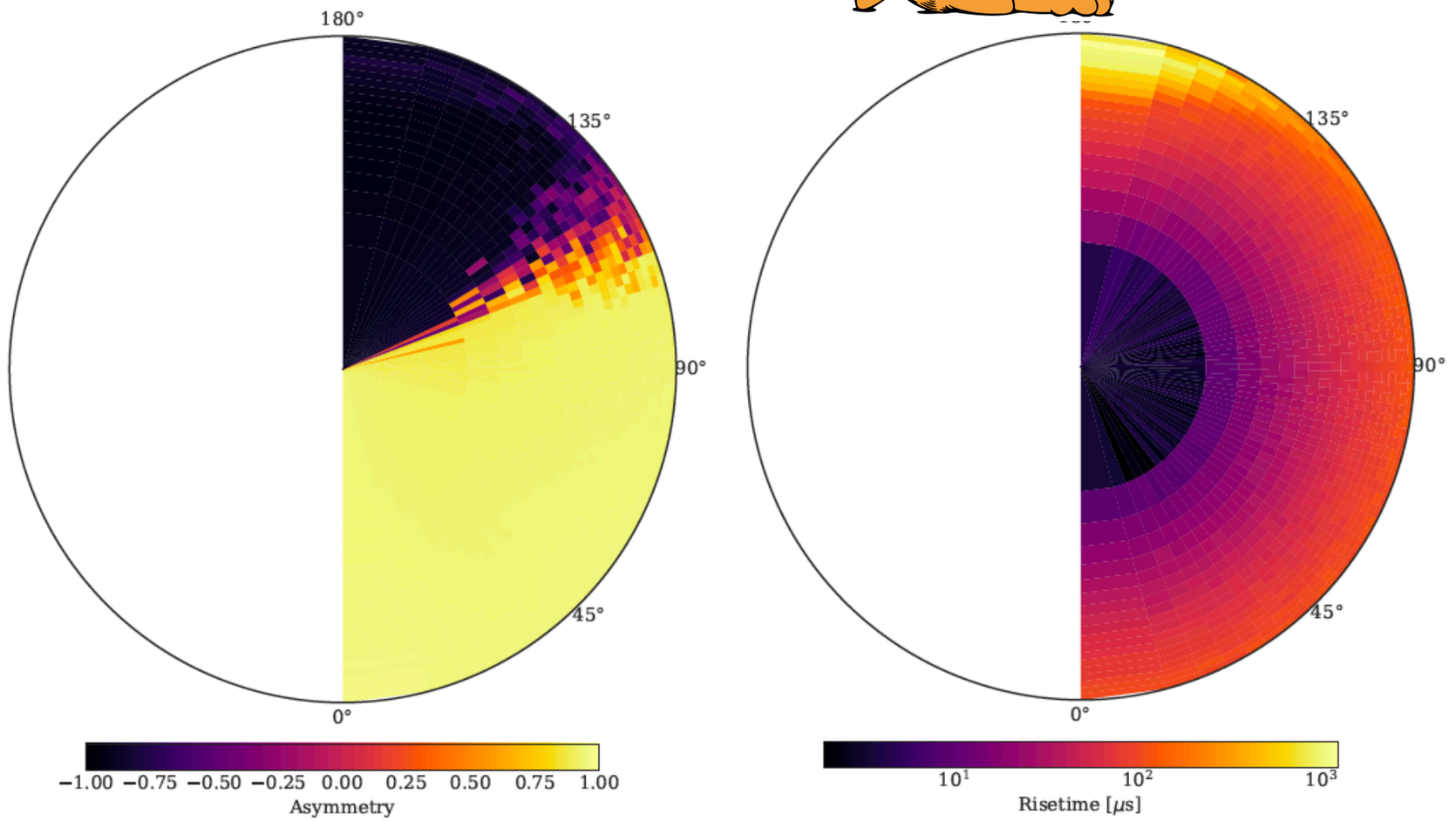


Fiducialisation

Birmingham simulation framework, combining strengths of Geant4 and Garfield++

JINST 15 (2020) 06, C06013

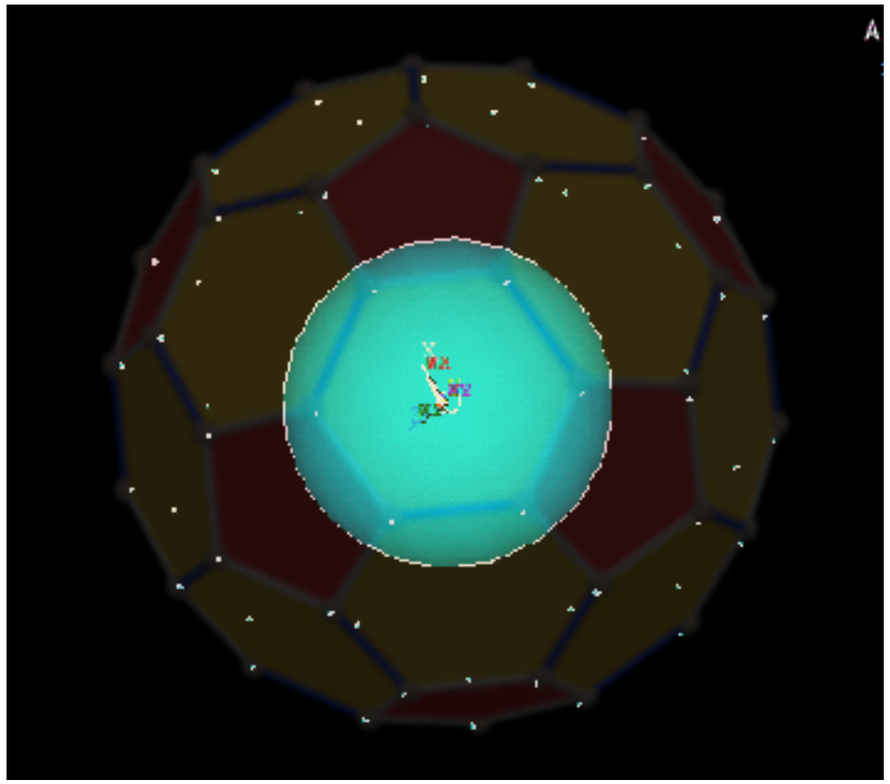




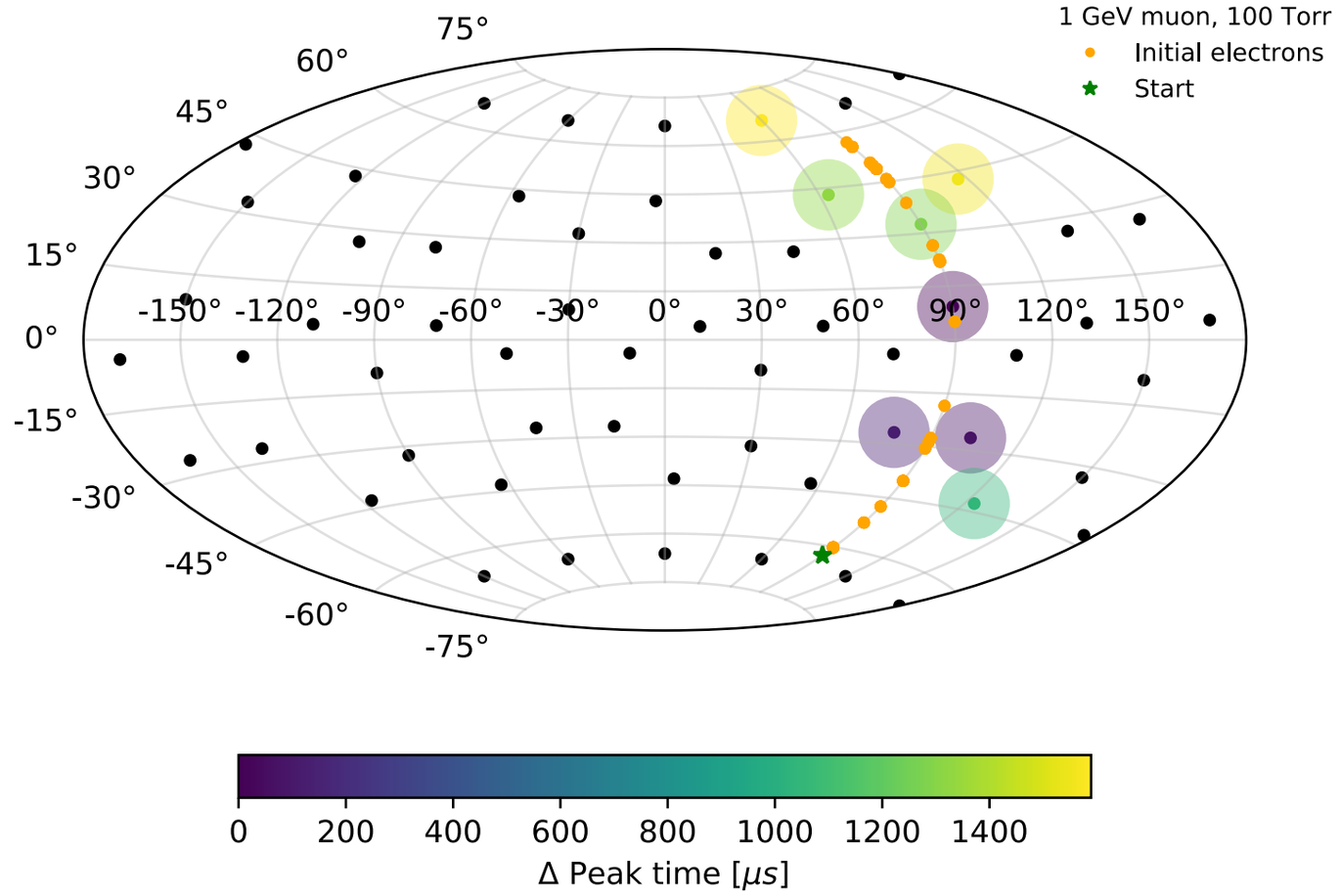
- Reading out individual ACHINOS anodes: position of interaction can be reconstructed
- First tests: Separate the anodes in two electrodes “Near” and “Far” (from the rod)
  - Asymmetry of pulse amplitudes: zenith angle
  - Pulse rise-time: radius

Event reconstruction

Individual anode read-out: track reconstruction



60-anodes (truncated icosahedron)



Reducing Backgrounds

Higher purity materials

- **Copper common material for rare event experiments**
  - Strong, pure, inexpensive
  - No long-lived isotopes (^{67}Cu $t_{1/2}$=62h)
- **Backgrounds**
  - Cosmogenic and ^{238}U/^{232}Th decay chain

4N Aurubis AG Oxygen Free Copper (99.99% pure)

- Spun into two hemispheres
- Electron-beam welded together

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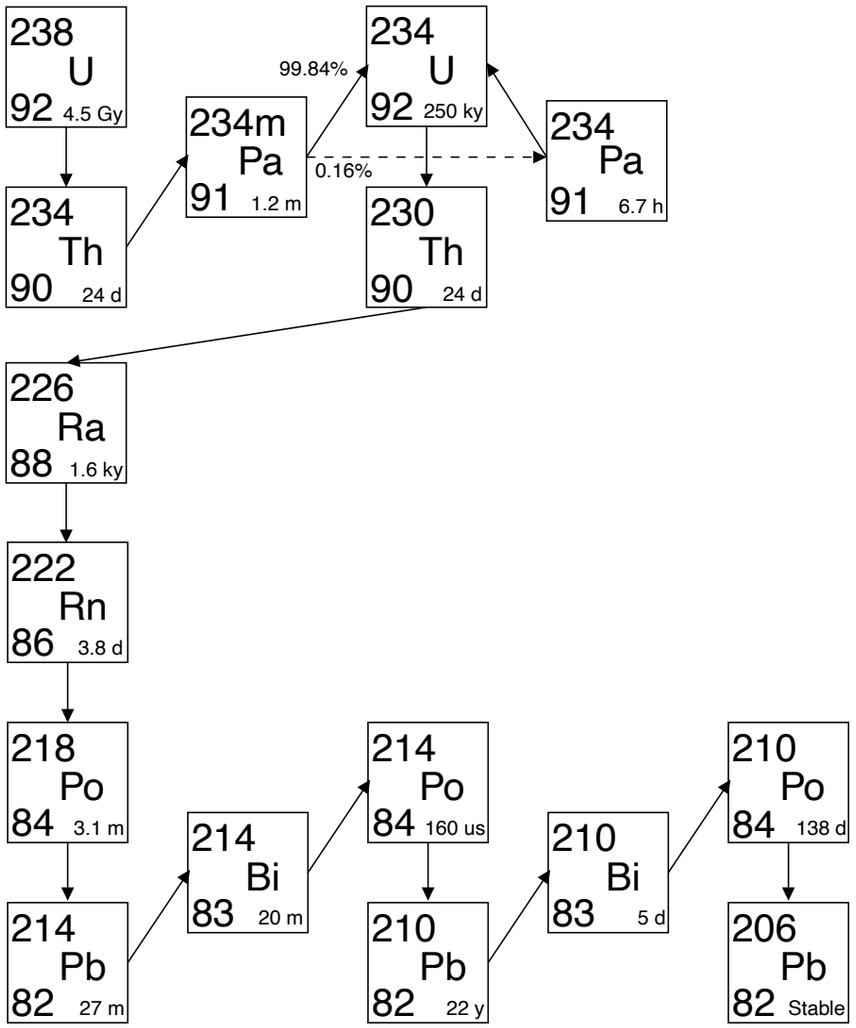

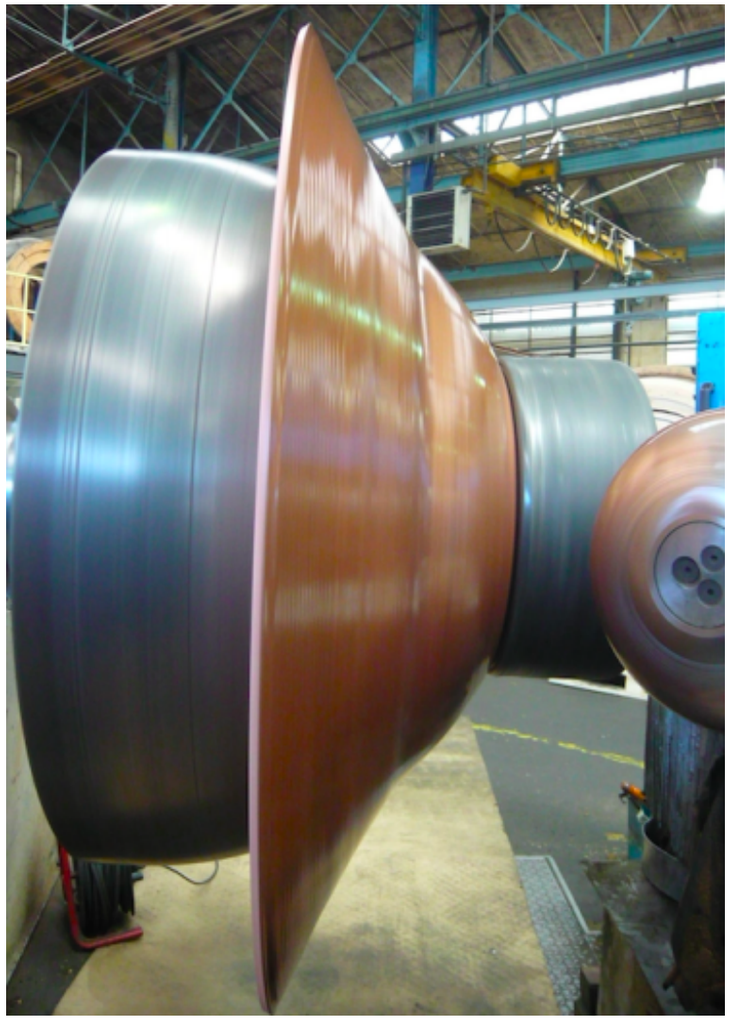

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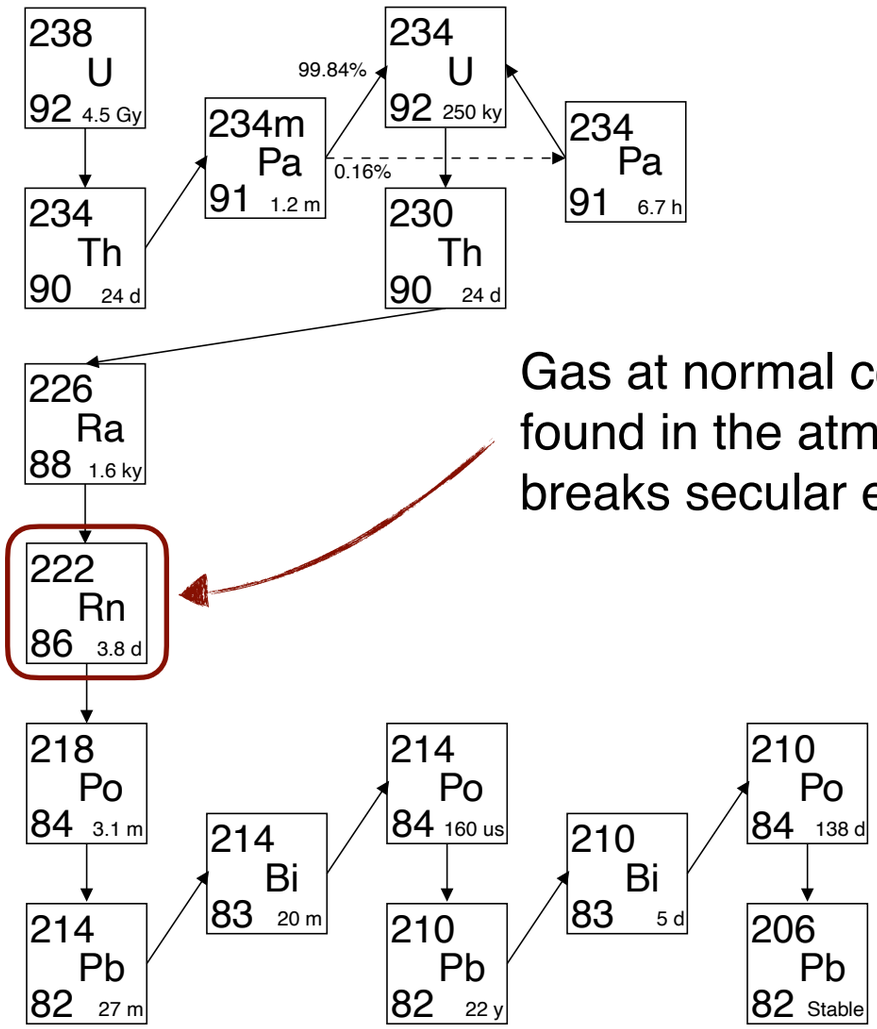
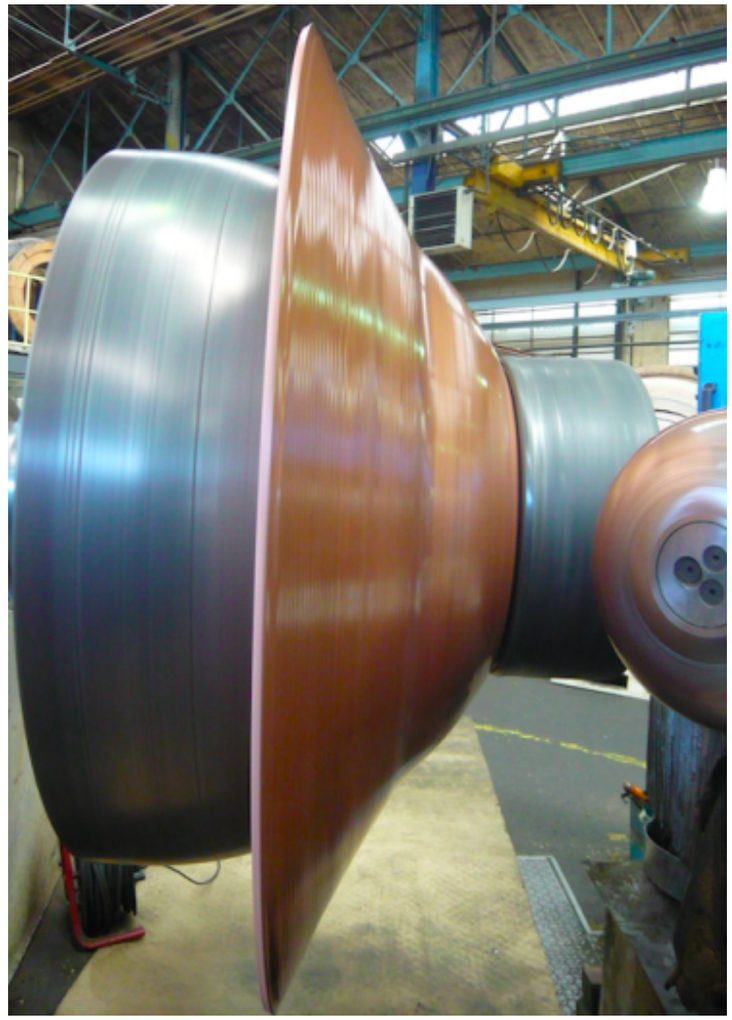


Gas at normal conditions: found in the atmosphere breaks secular equilibrium



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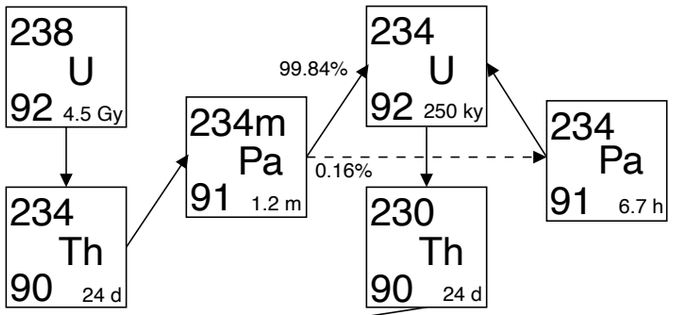

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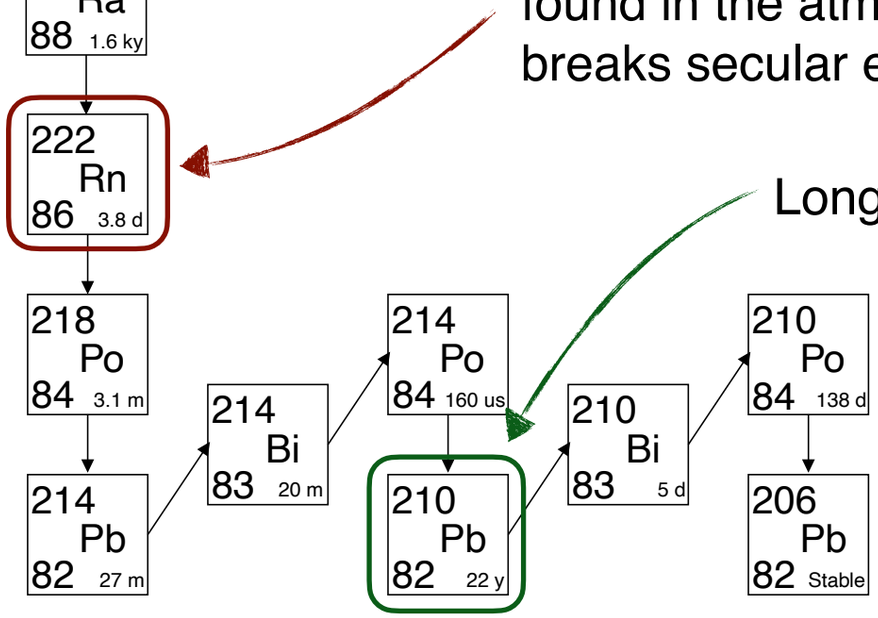
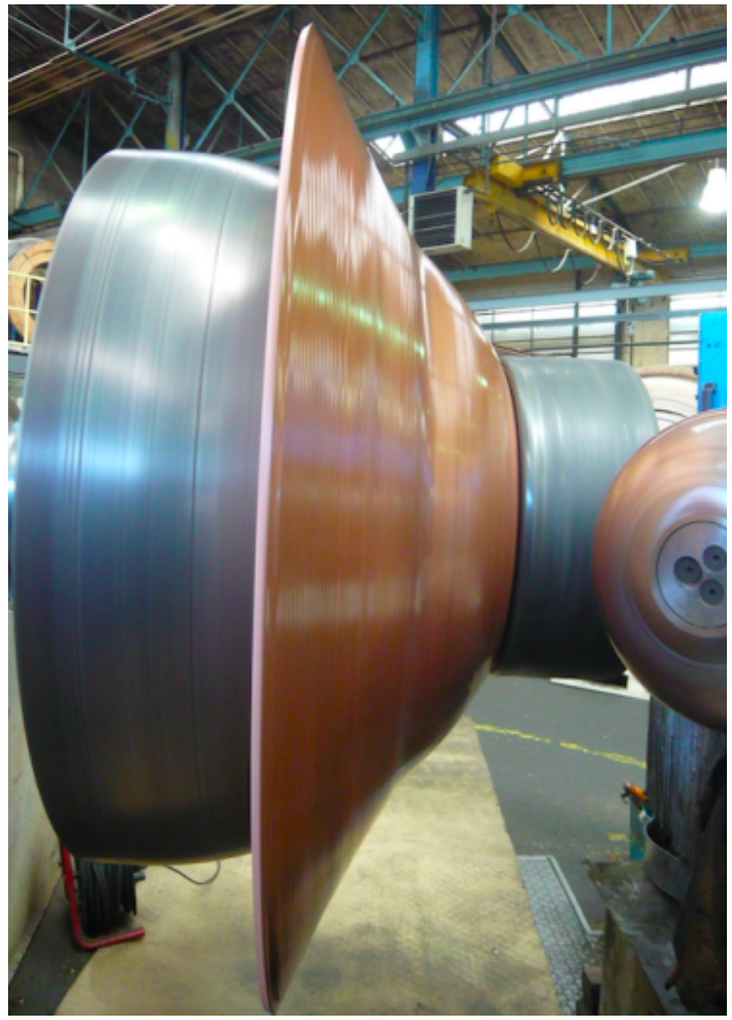


Long-lived!



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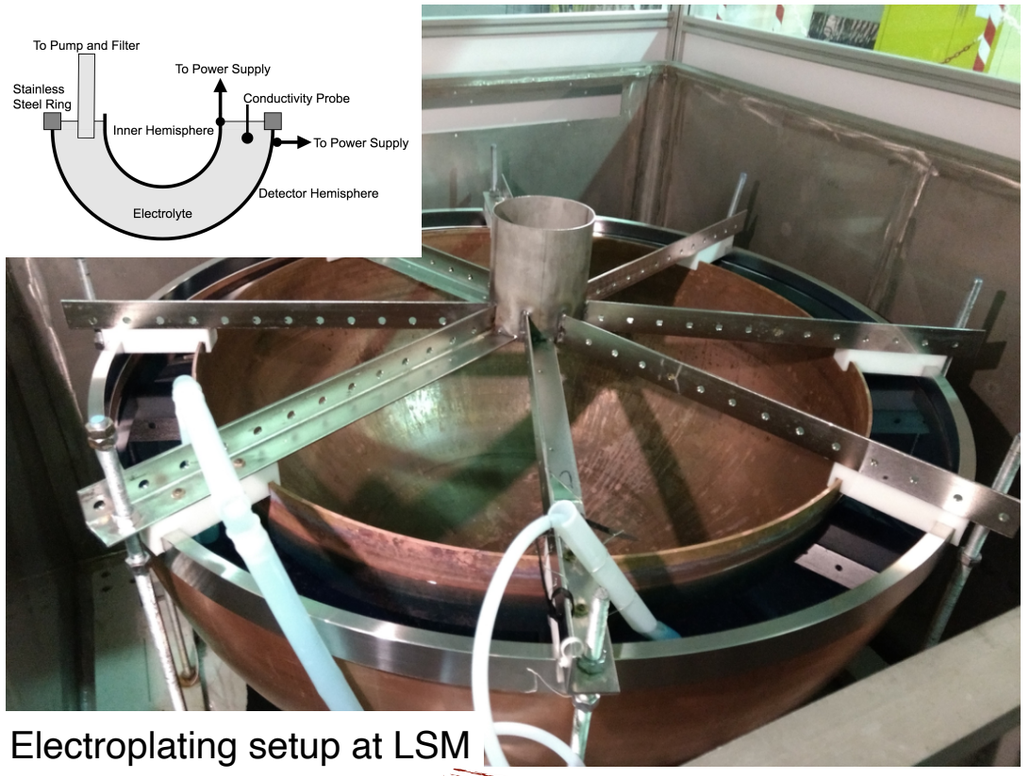
Copper Electroplating



Electroplating setup at LSM

Internal shield:

- add layer of extremely radio-pure copper
- 500µm deposited in 2 weeks (~36µm/day)

First large-scale underground radio-pure electroformation

- Crucial for next generation experiments!

See talk by Ioannis Katsioulas

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journal homepage: www.elsevier.com/locate/nima

Copper electroplating for background suppression in the NEWS-G experiment

L. Balogh [a], C. Beaufort [b], A. Brossard [a], R. Bunker [c], J.-F. Caron [a], M. Chapellier [a], J.-M. Coquillat [a], E.C. Corcoran [d], S. Crawford [a], A. Dastgheibi Fard [b], Y. Deng [e], K. Dering [a], D. Durnford [e], G. Gerbier [a], I. Giomataris [f], G. Giroux [a], P. Gorel [g,h,i], M. Gros [f], P. Gros [a], O. Guillaudin [b], E.W. Hoppe [c], I. Katsioulas [j], F. Kelly [d], P. Knights [f,j,*], L. Kwon [d], S. Langrock [h], P. Lautridou [k], R.D. Martin [a], J.-P. Mols [f], J.-F. Muraz [b], X.-F. Navick [f], T. Neep [j], K. Nikolopoulos [j], P. O'Brien [e], R. Owen [j], M.-C. Piro [e], D. Santos [b], G. Savvidis [a], I. Savvidis [l], F. Vazquez de Sola Fernandez [a], M. Vidal [a], R. Ward [j], M. Zampaolo [b]

(NEWS-G Collaboration)

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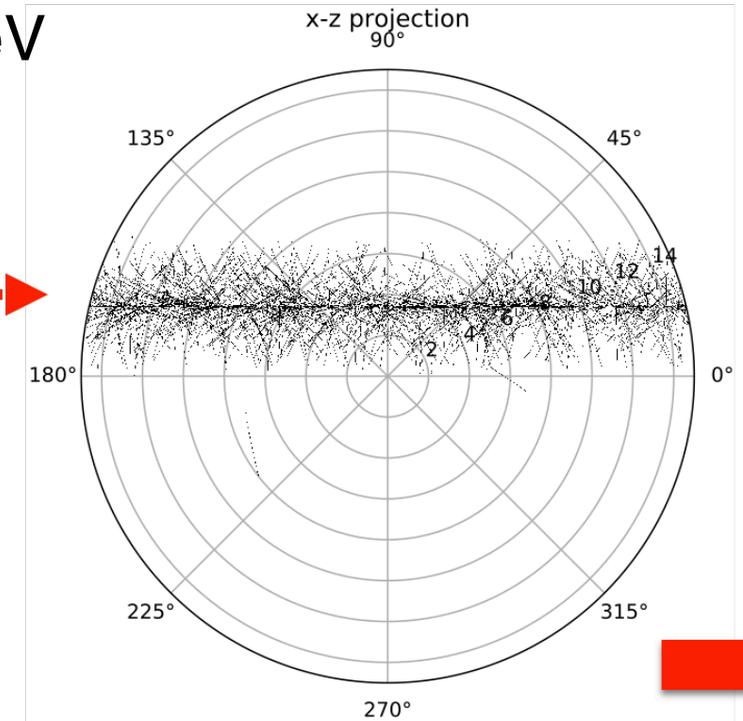
[m] Kamioka Observatory, ICRR, University of Tokyo, Higashi-Mozumi, Kamioka, Hida, Gifu 506-1205, Japan
[n] Kavli Institute for the Physics and Mathematics of the Universe, University of Tokyo, Kashiwa, Chiba 277-8582, Japan

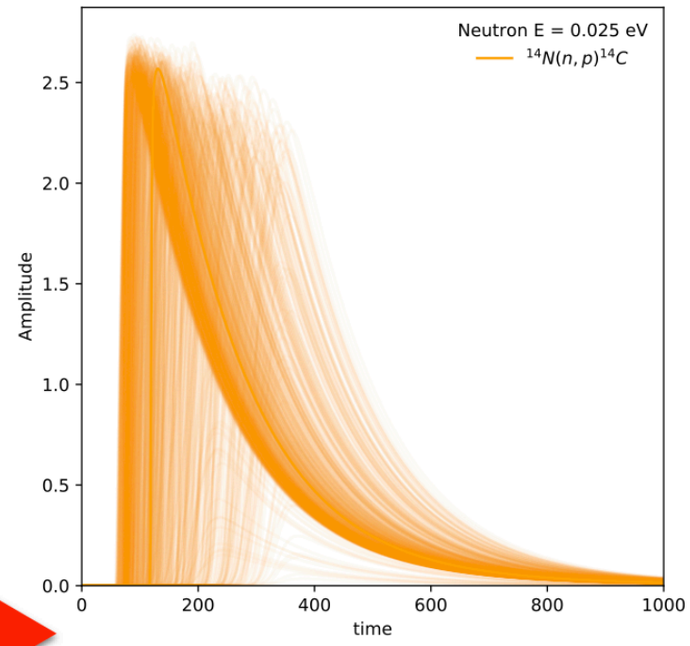
In-situ neutron background measurements

- Neutrons: critical background in DM searches
- Underground measurements scarce
- Nitrogen gas
  - $^{14}N+n \rightarrow {}^{14}C+p$ + 625 keV
  - $^{14}N+n \rightarrow {}^{11}B+\alpha$ - 159 keV

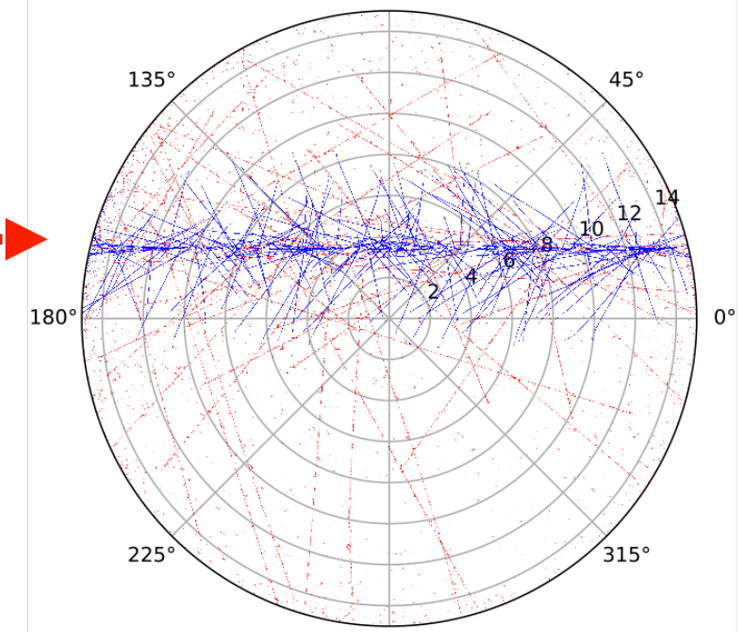
Neutron Beam
0.025 eV

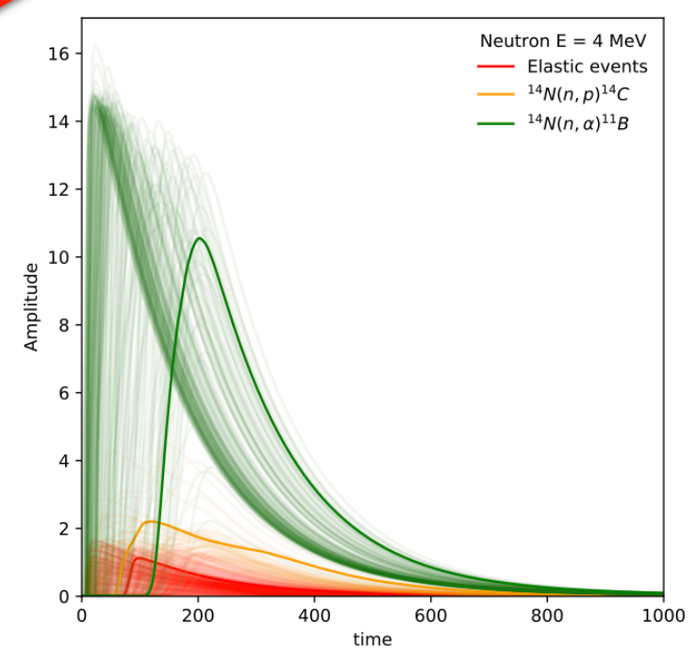
Parameters
Ø30cm vessel
N_2 at 300mbar
Ø2mm anode



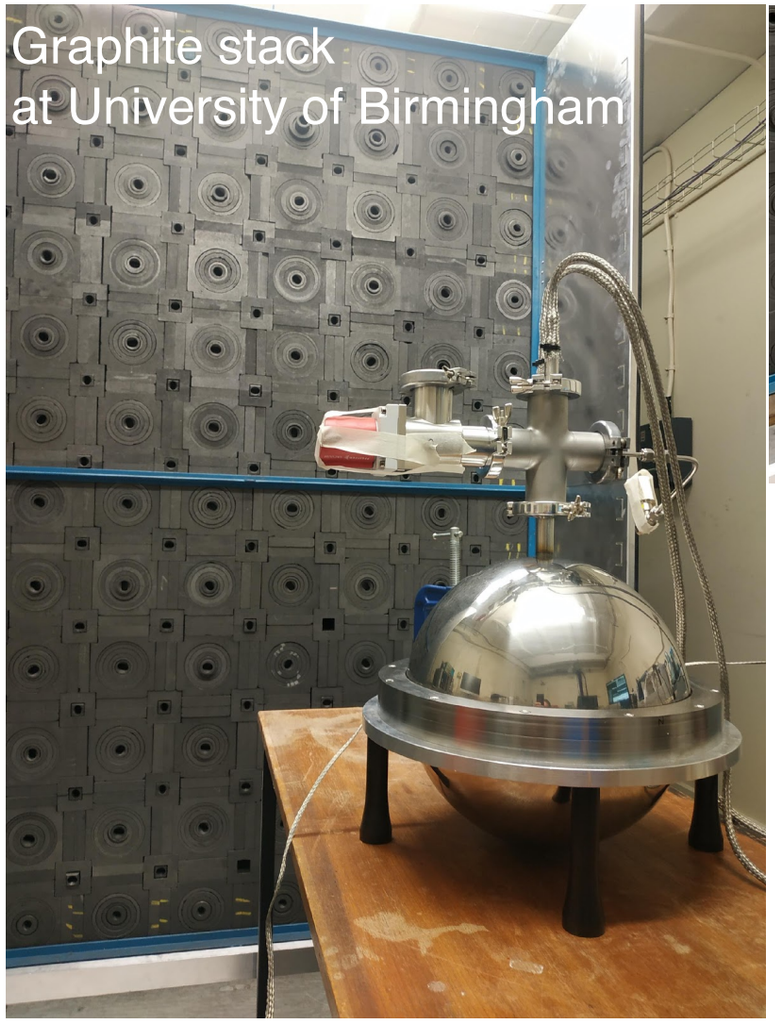


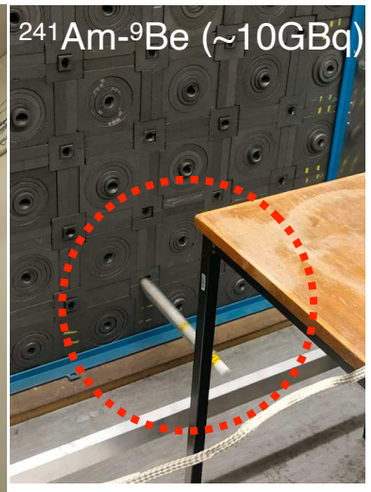
Neutron Beam
4 MeV



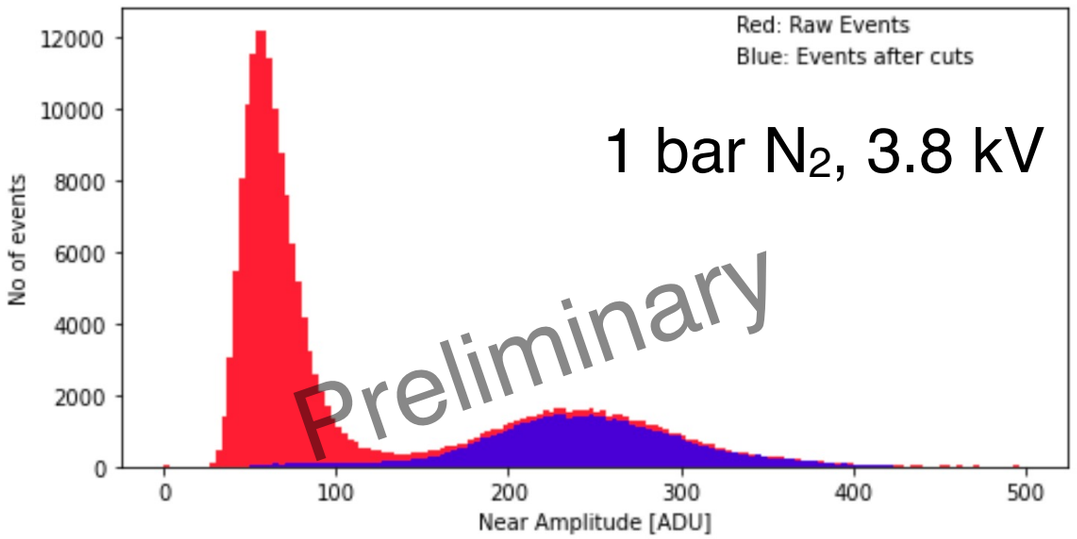


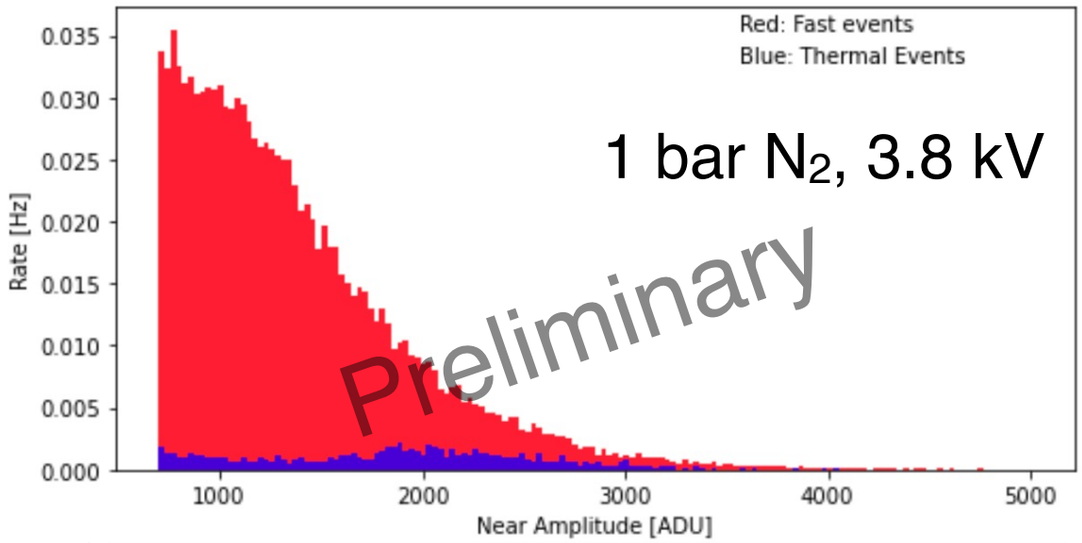
In-situ neutron background measurements

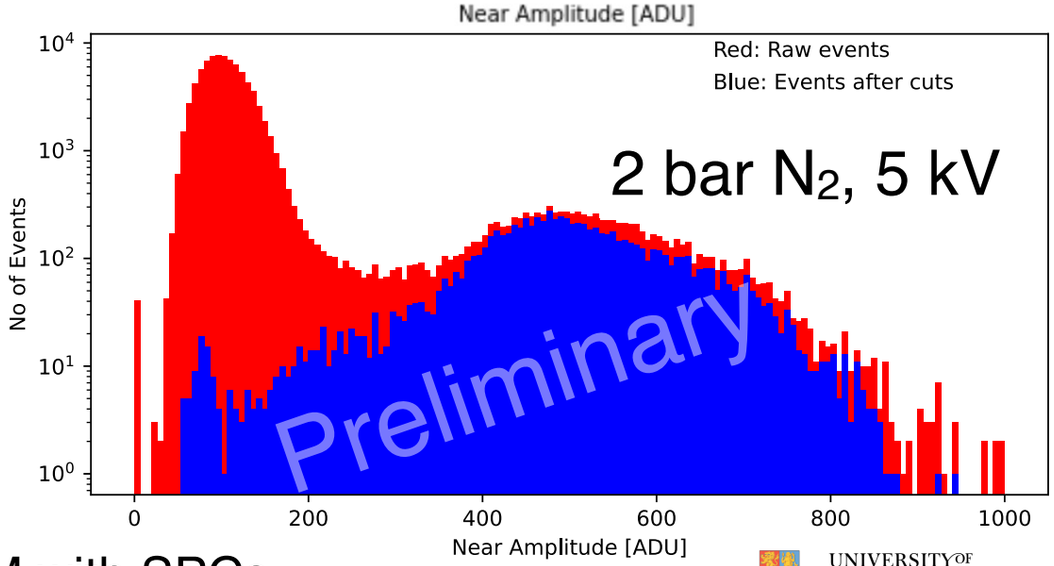




- Spherical Proportional Counter
  - ∅ 30 cm
  - N_2 gas
- Multi-anode sensor
  - 11 anodes
  - ∅ 1mm
  - 2 channel read-out

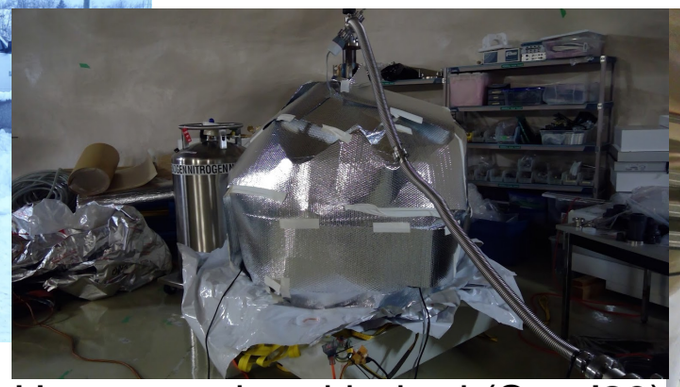




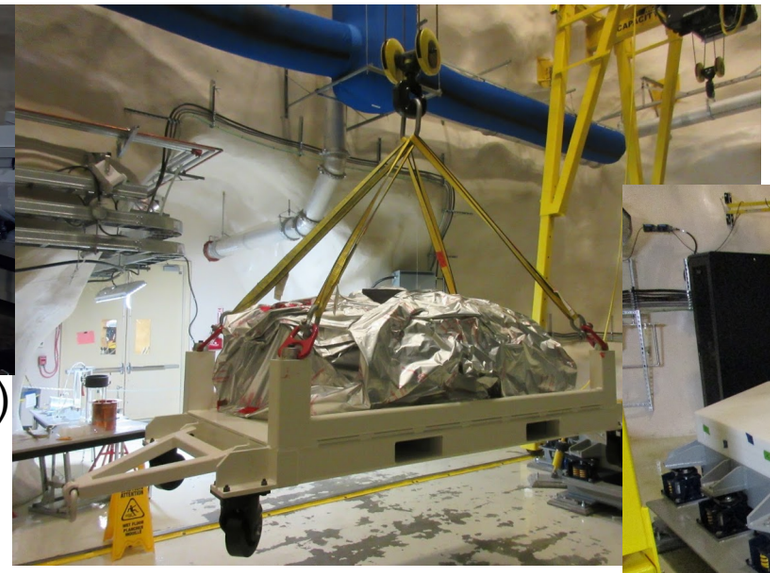


Installation at SNOLAB

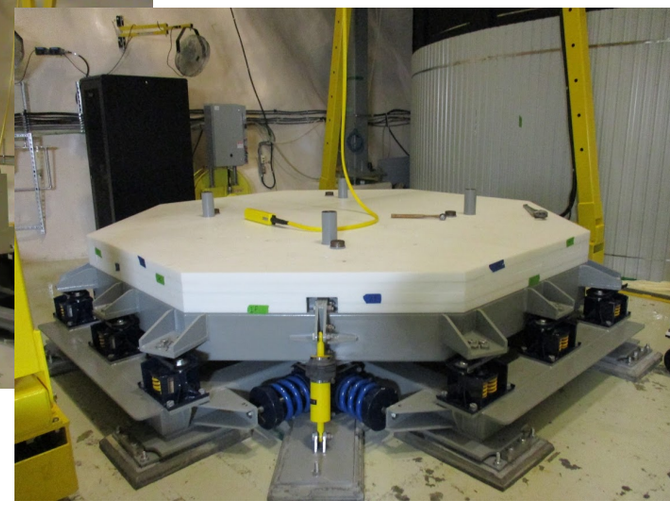
Arrival at SNOLab (Dec ’19)



Unwrapped and baked (Sep ’20)

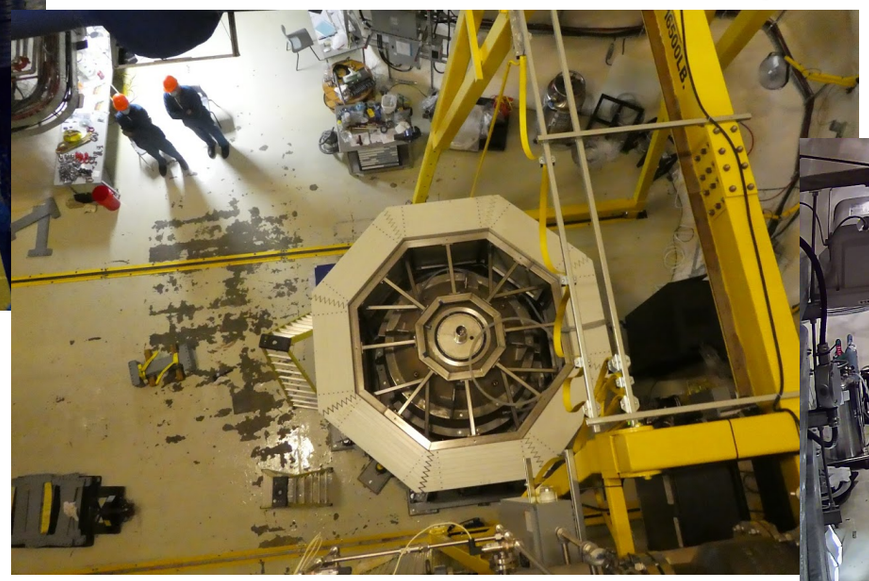


Pb shielding arrival



Seismic platform installation

Detector Installation

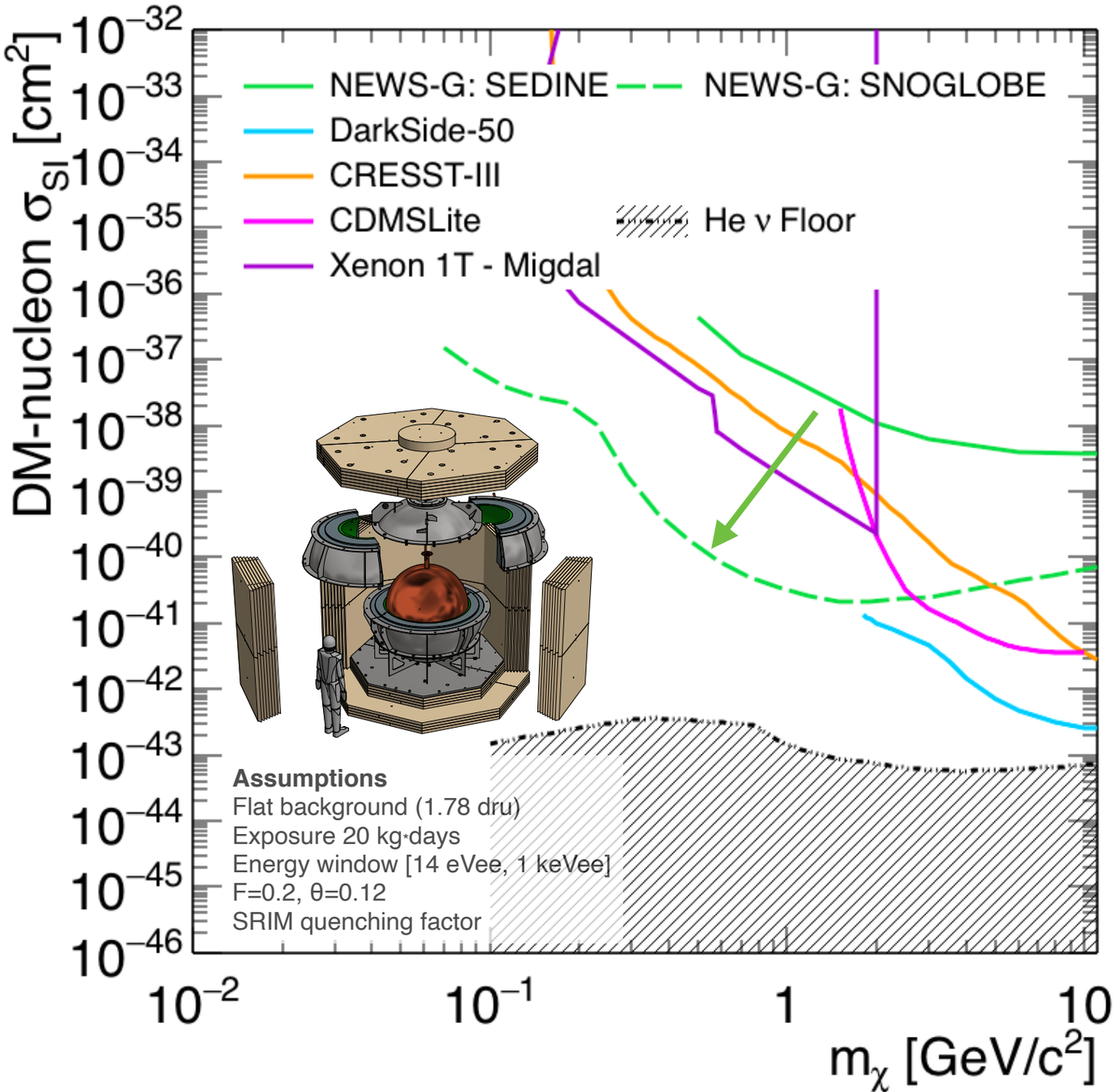


PE shielding installation

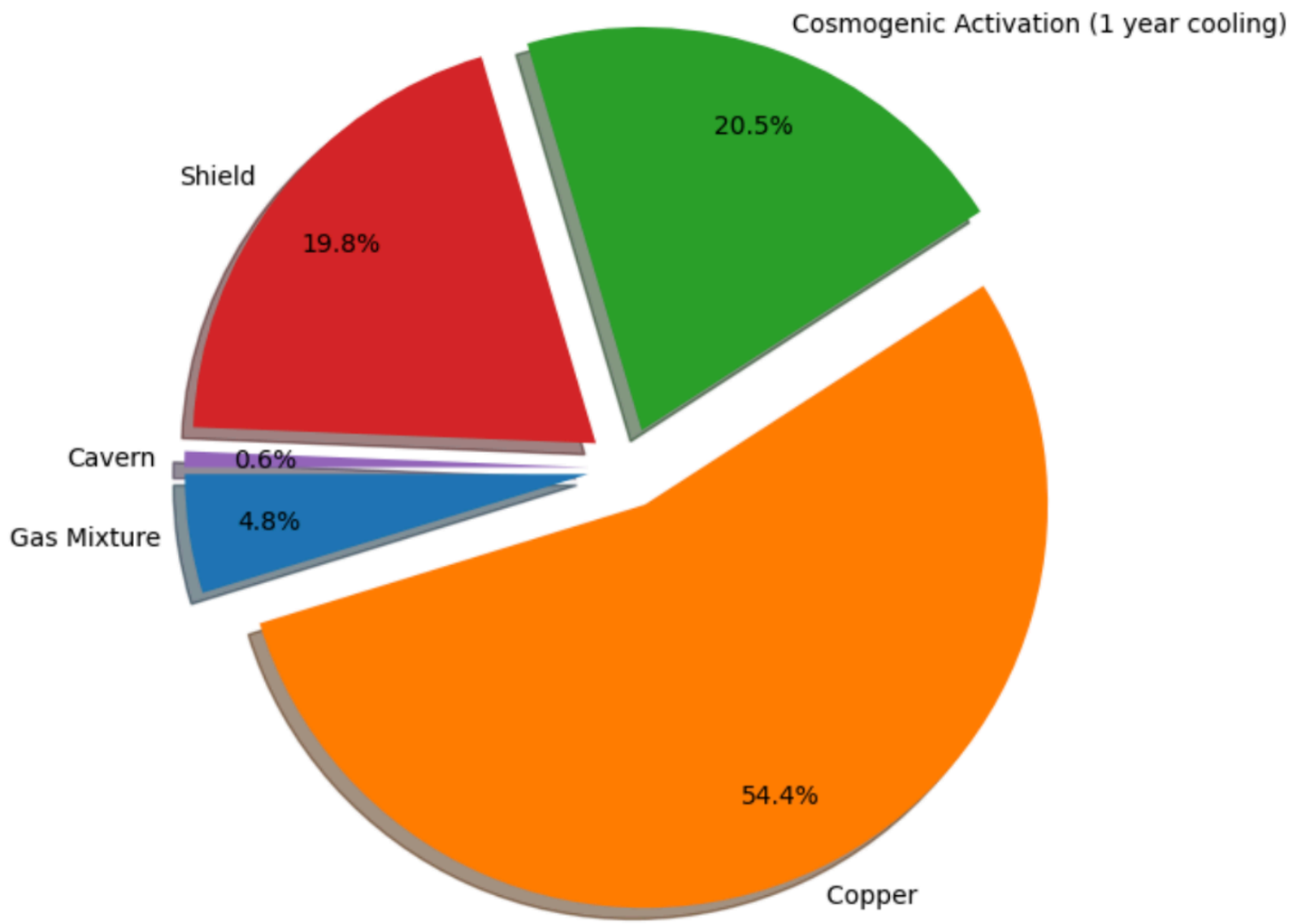
SNOGLOBE complete

NEWS-G at SNOLAB: Physics Potential

Data-taking is starting!



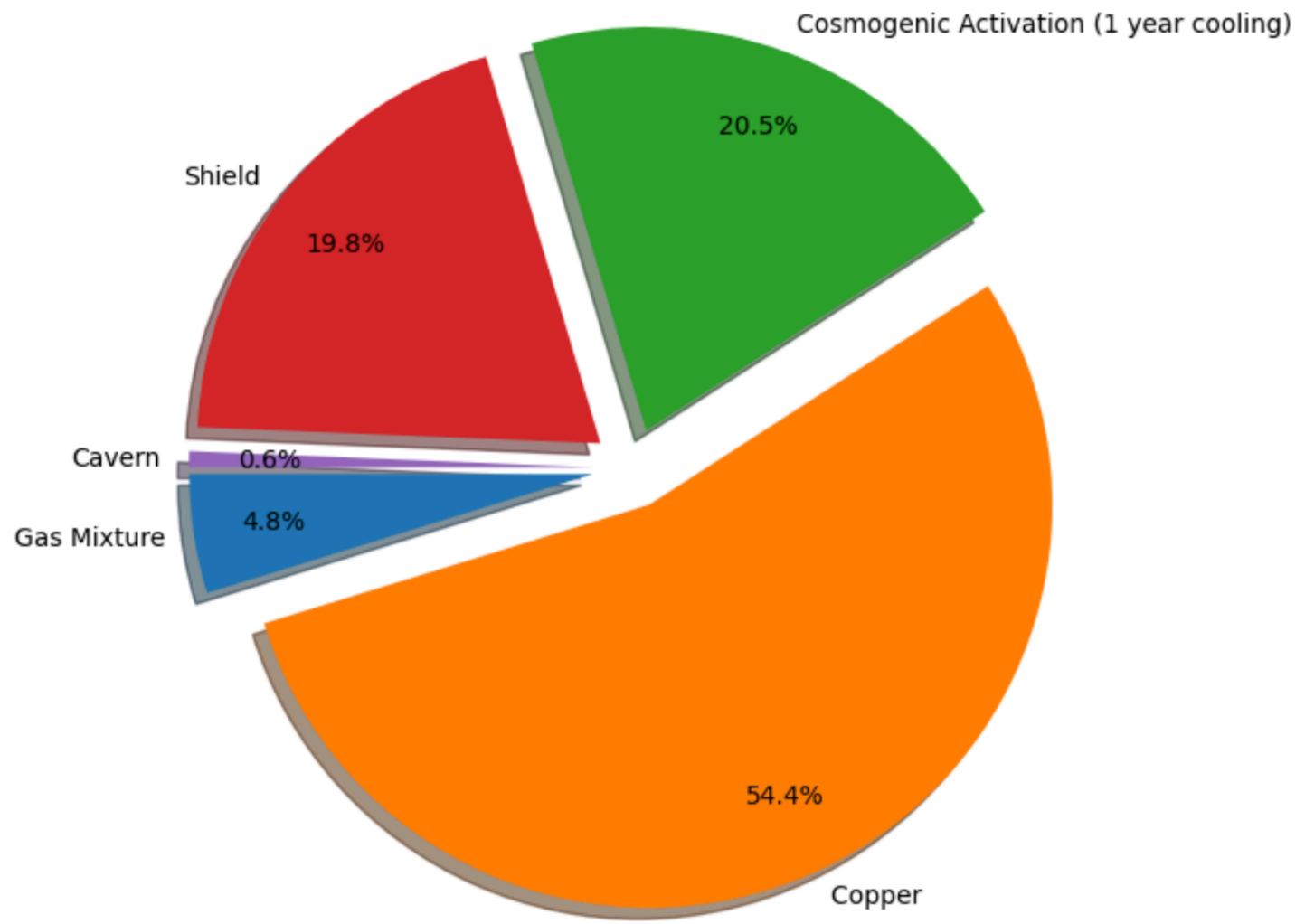
Fully electroformed detectors



Fully electroformed detectors

Intact underground electroformed spheres

- Scale model to be constructed this summer
- ⌀140cm detector later this year!



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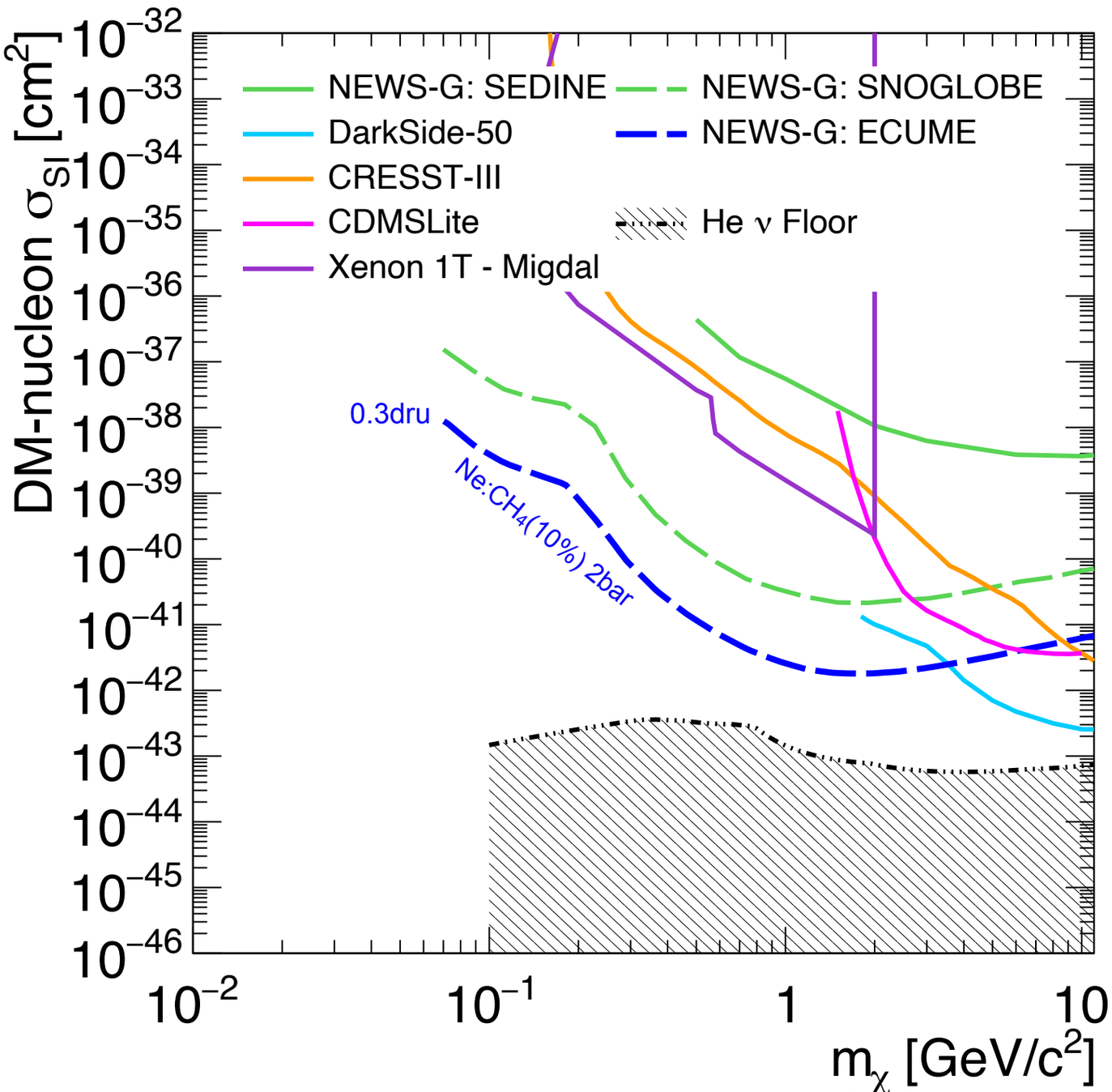
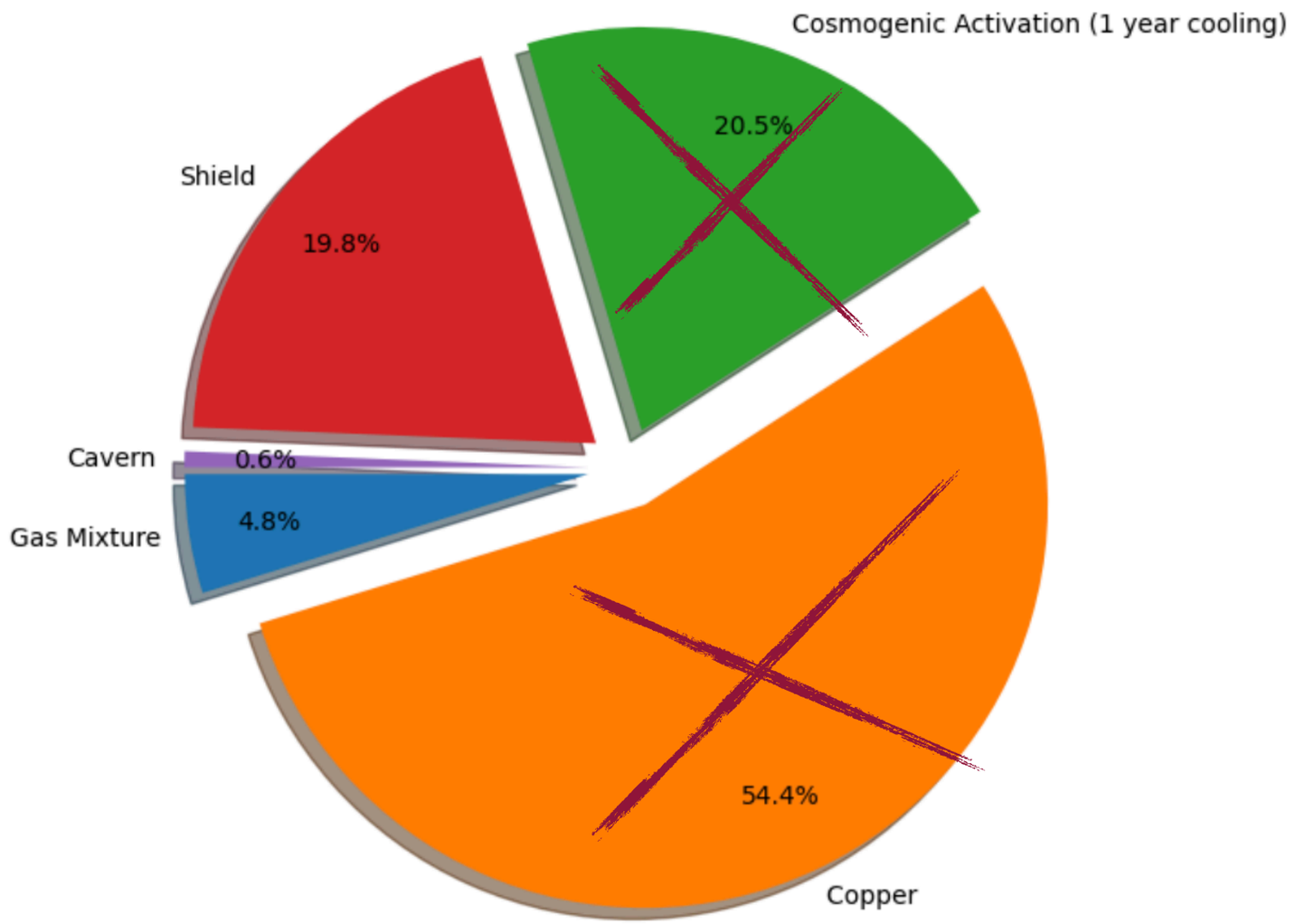
ECuME

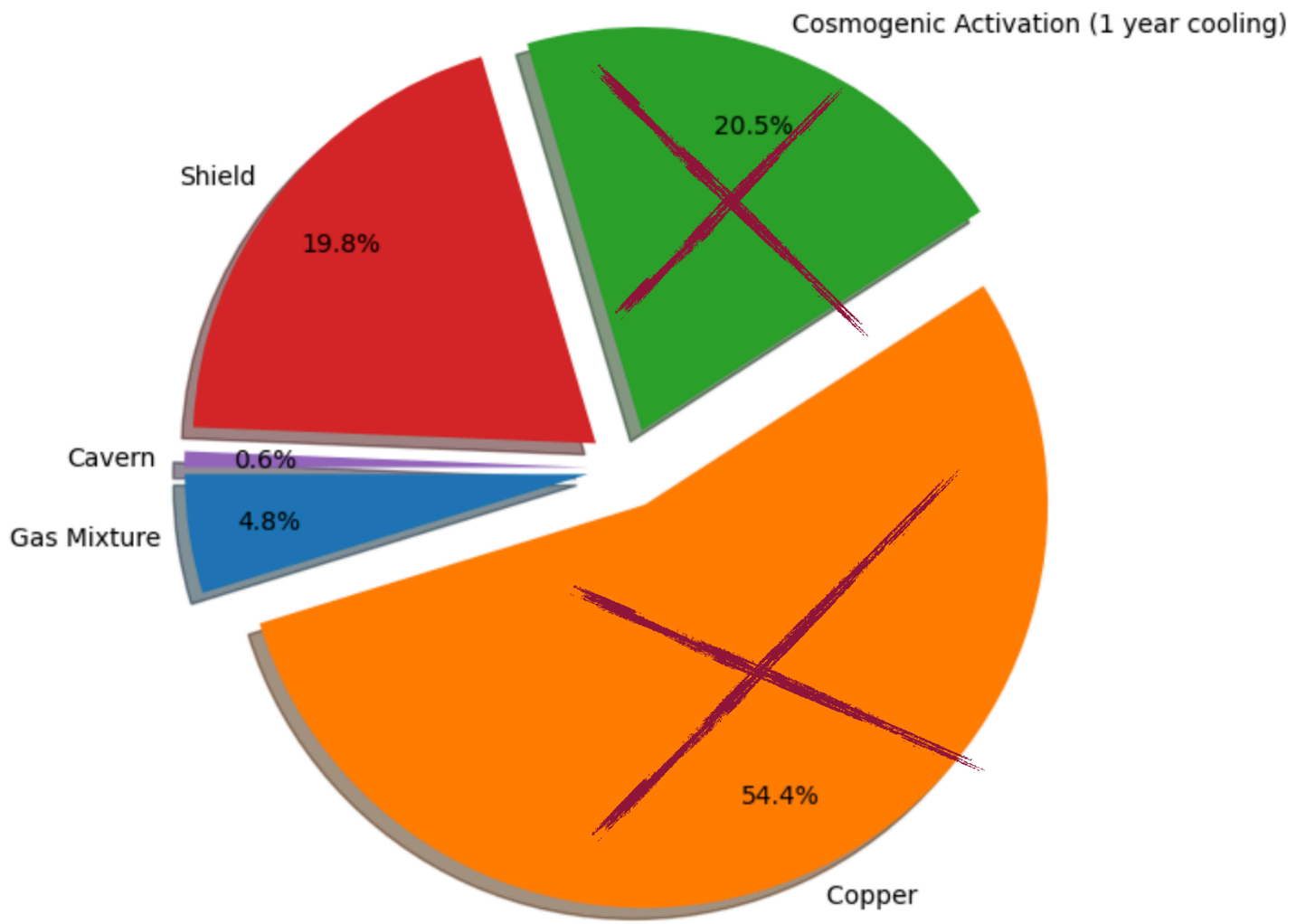


Reaching the neutrino floor



Reaching the neutrino floor

Scale volume ×10 and improve shielding

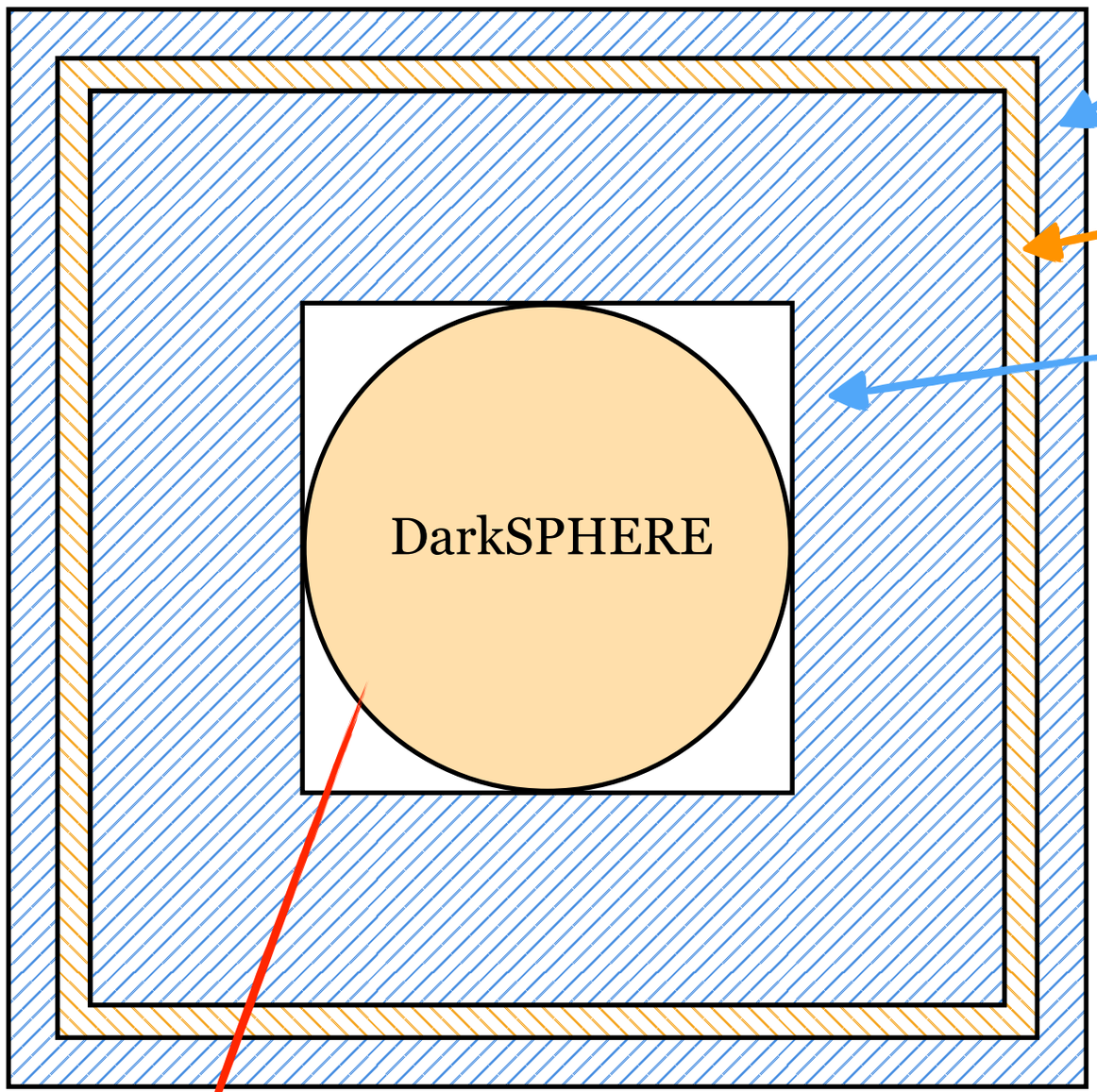


DarkSPHERE

Volume ×10: ⌀300cm intact underground electroformed spherical proportional counter
Shielding: Full water shielding option and water/lead option

Configuration	Photons [dru]	Neutrons [dru]
Water (2 m)	8	0.002
Water (3.5 m)	0.002	<0.002
Water-lead	0.005	0.002

Assuming installation at Boulby



Operation with 5 bar He:C_4H_{10} (90%:10%) (27 kg)

DarkSPHERE: Physics Potential

Multi-physics platform:

- Dark matter
- 0νββ searches
- Neutrino physics

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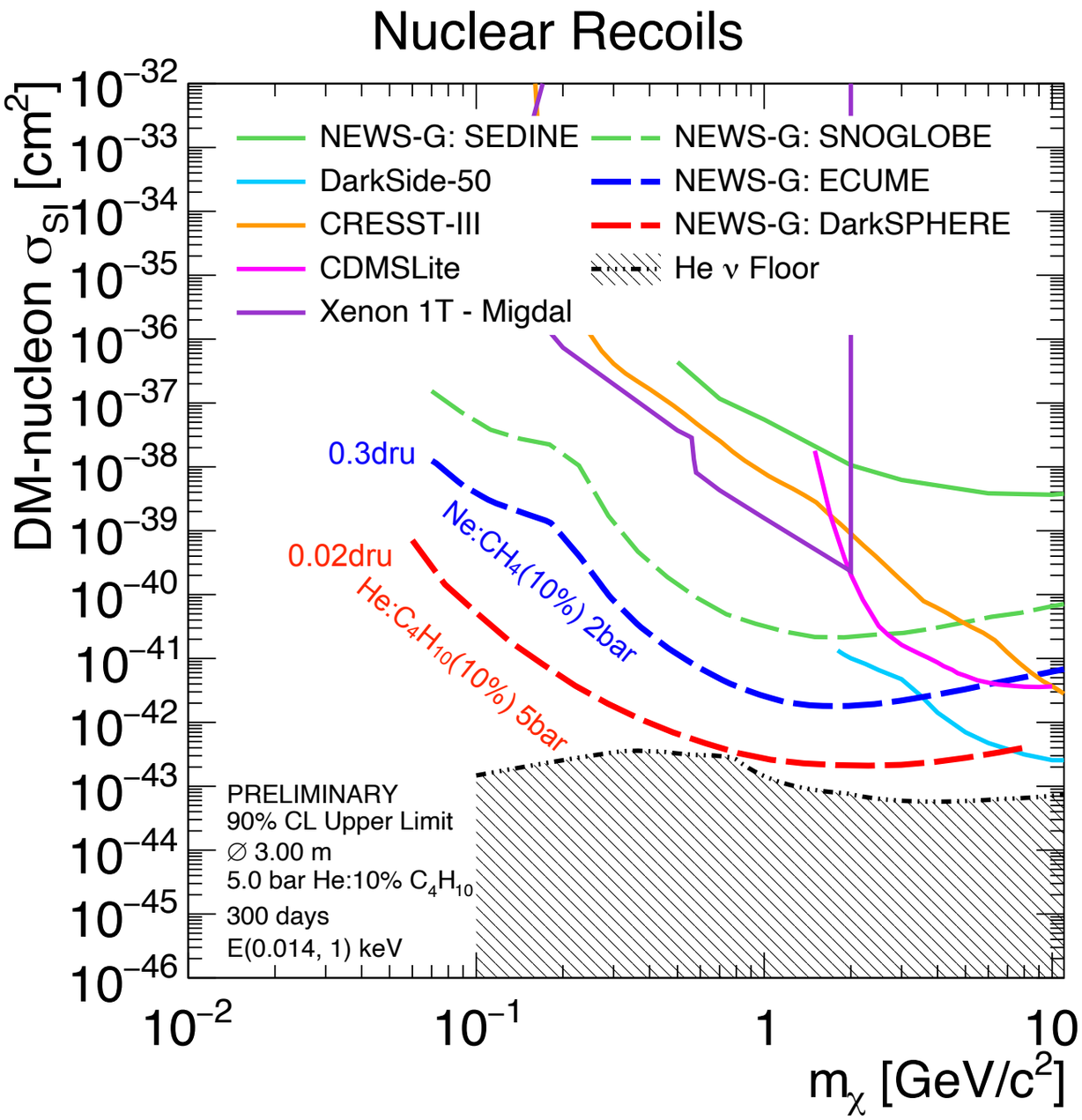

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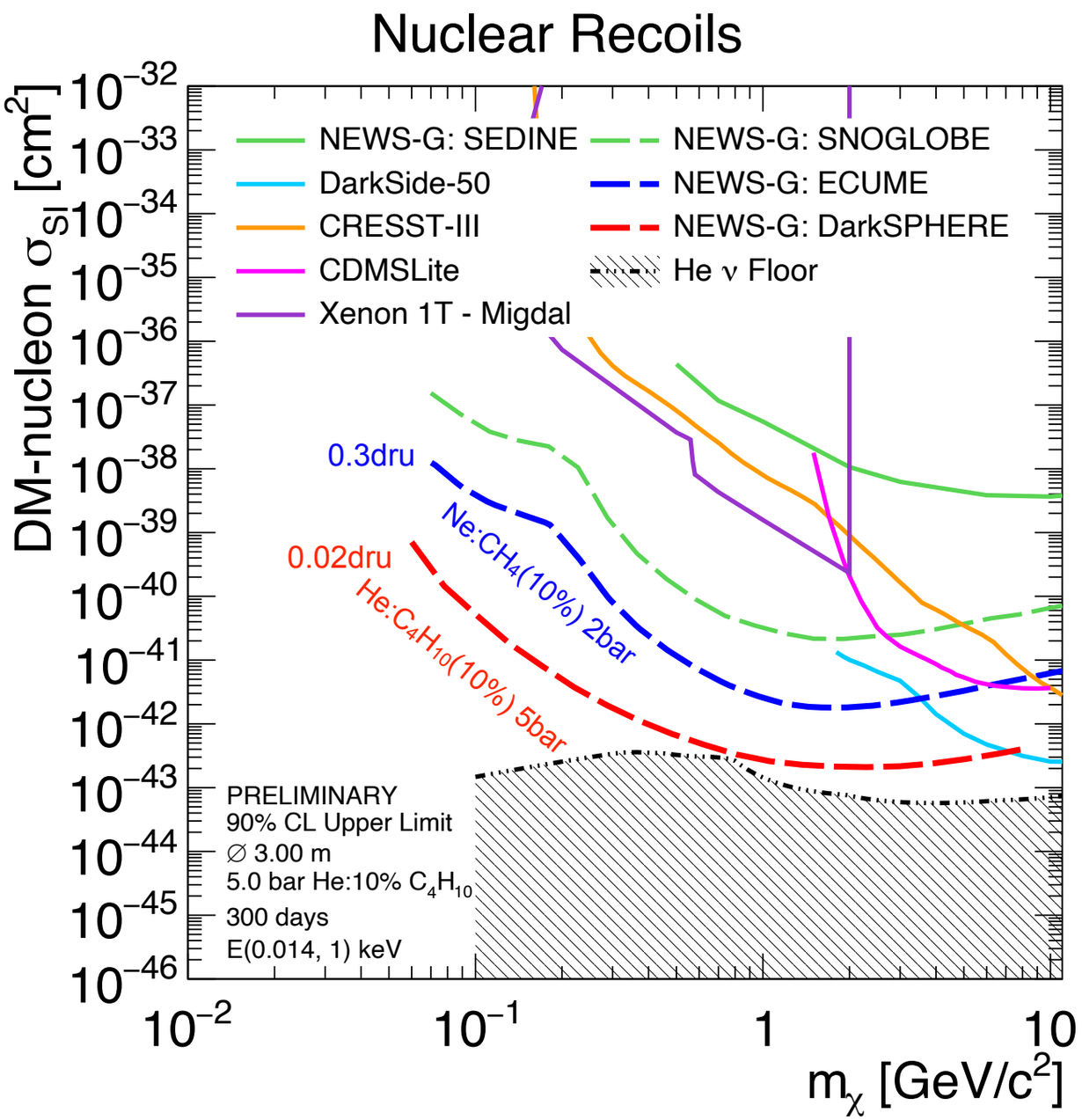

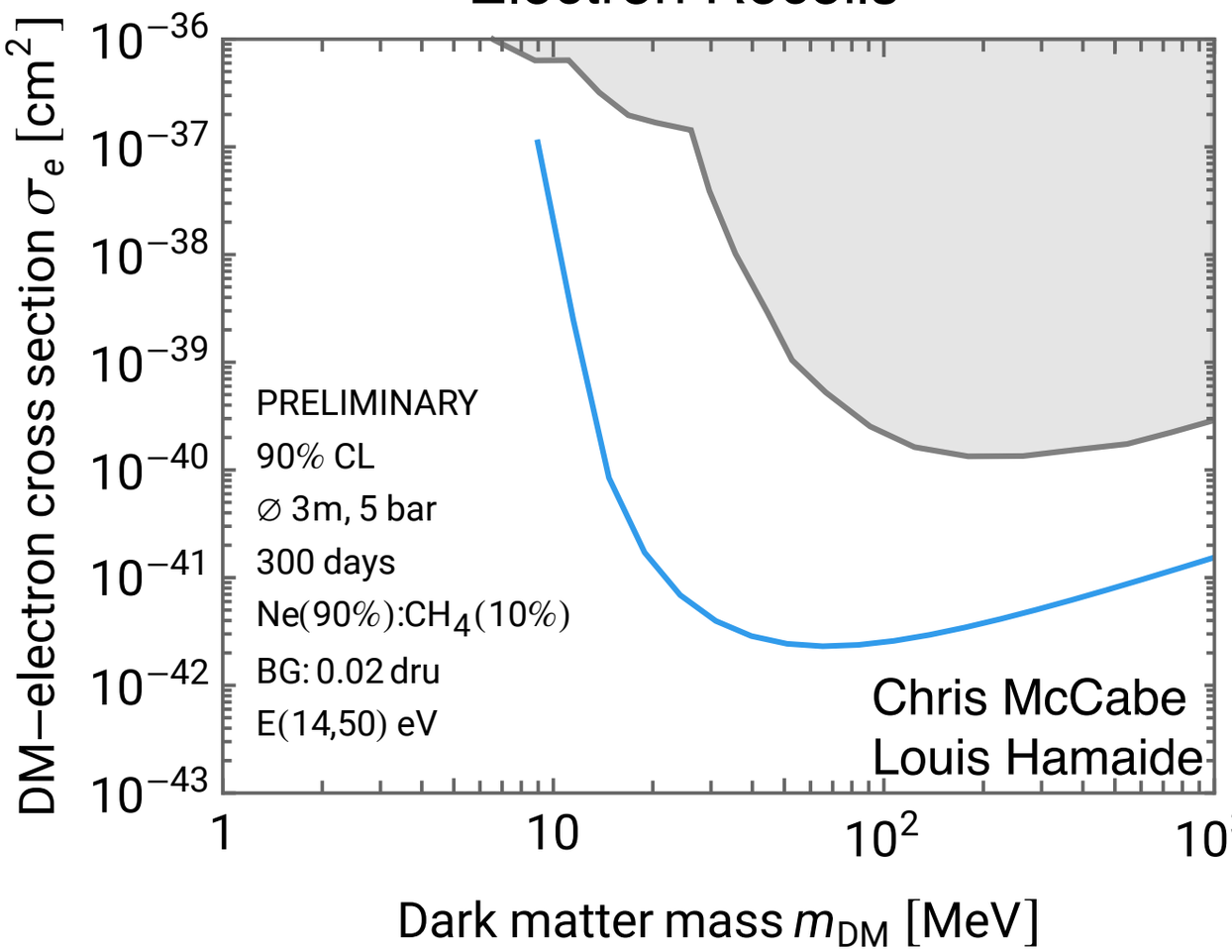

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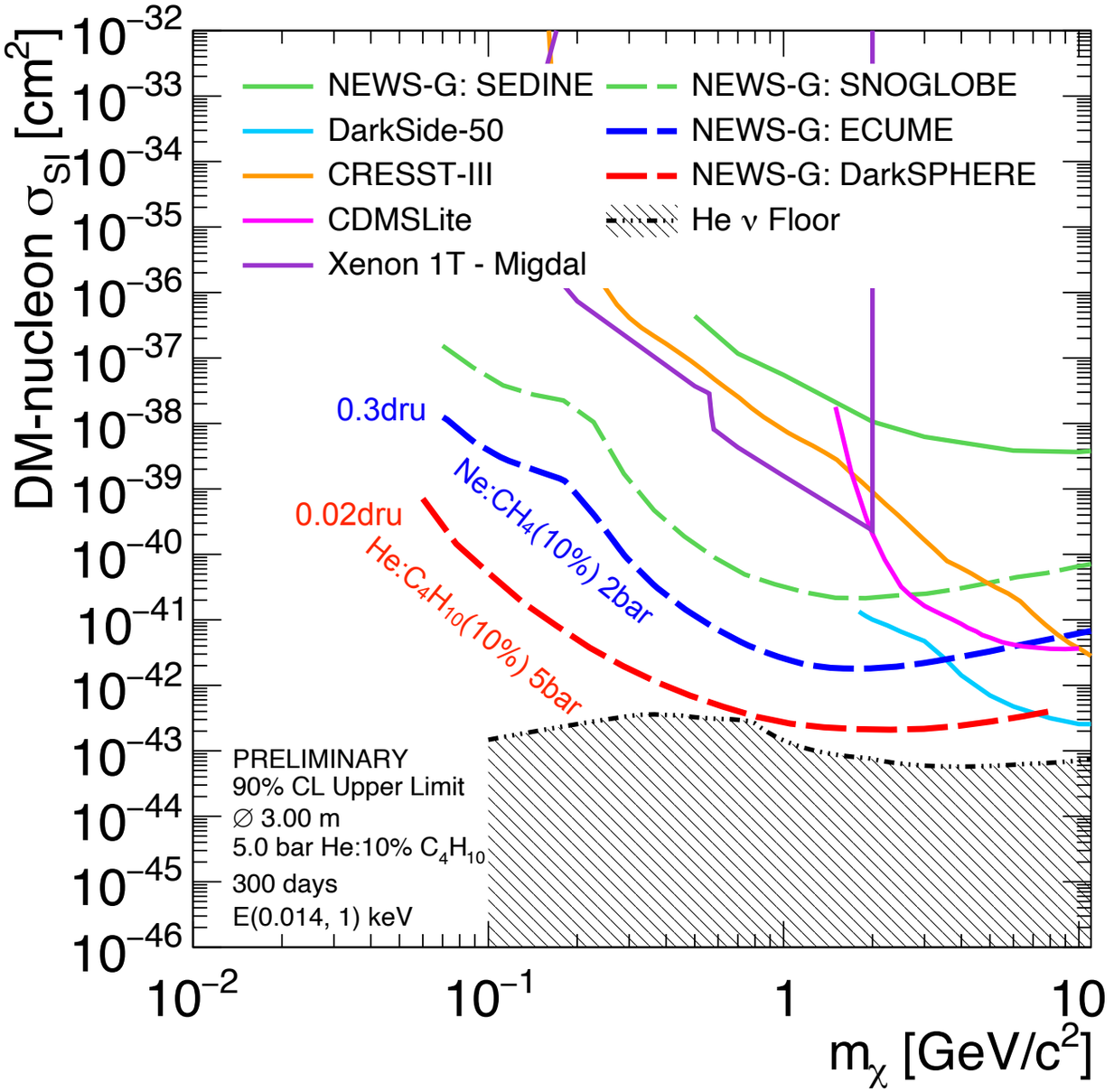
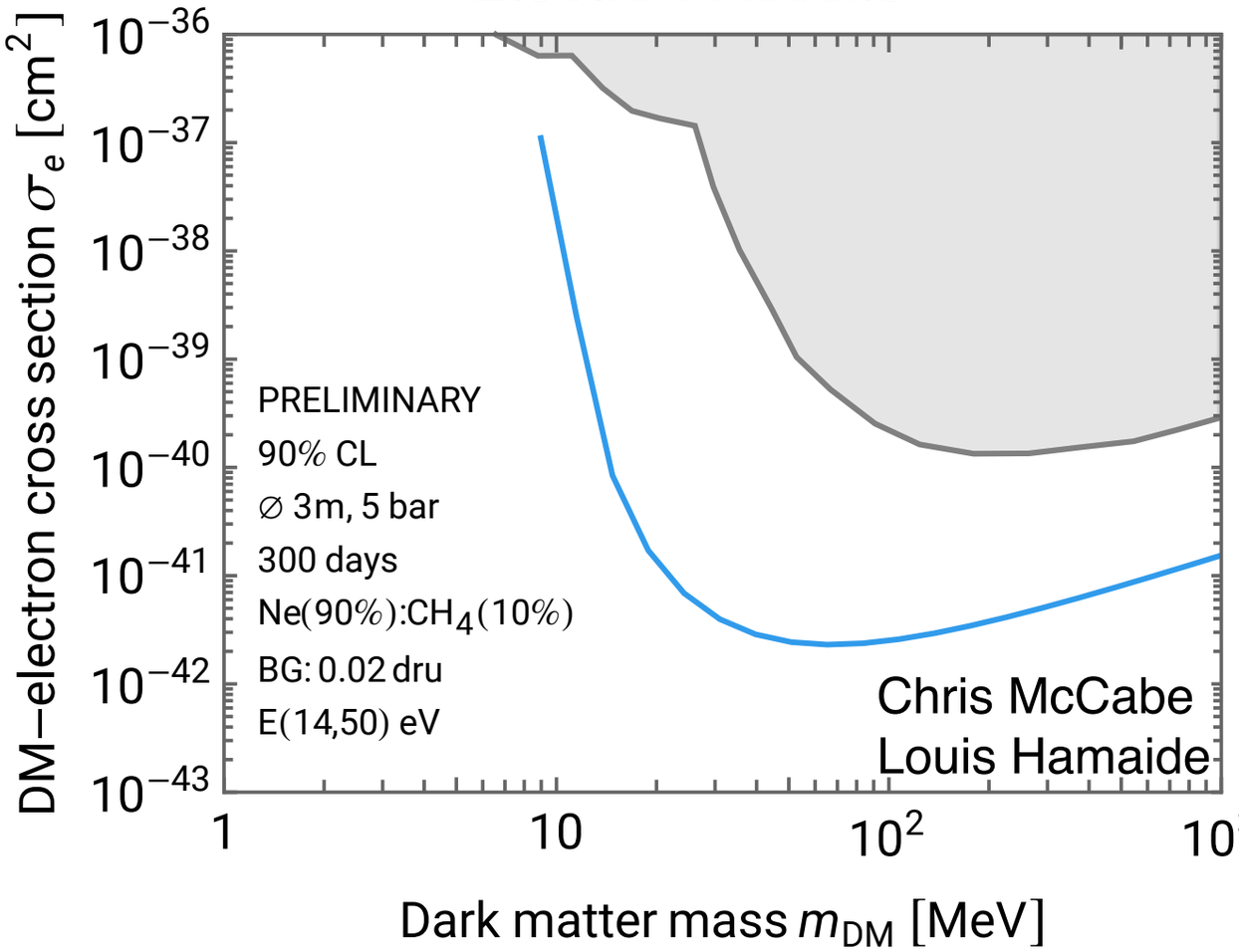
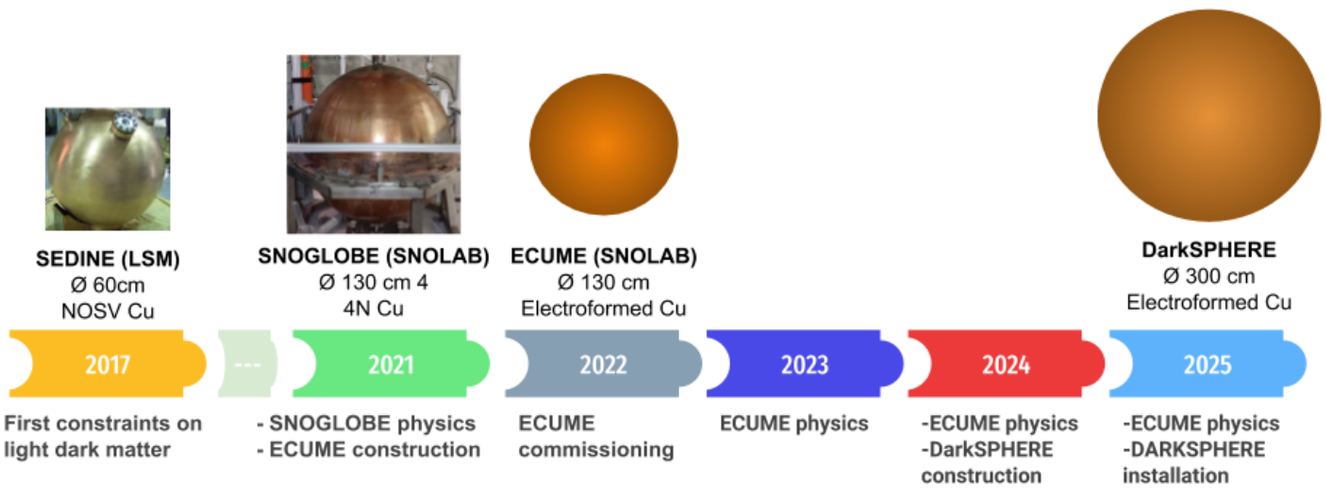
Nuclear Recoils



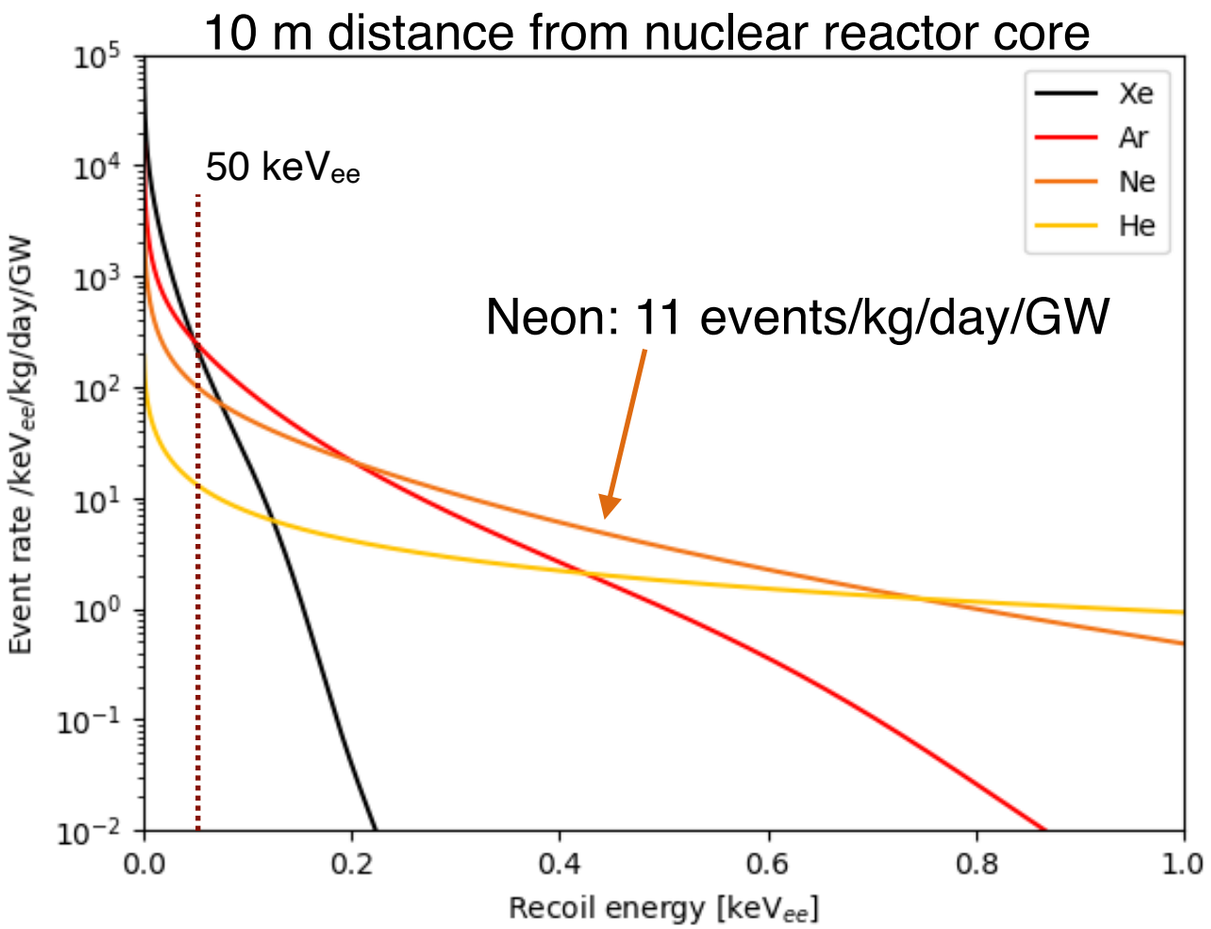
Electron Recoils

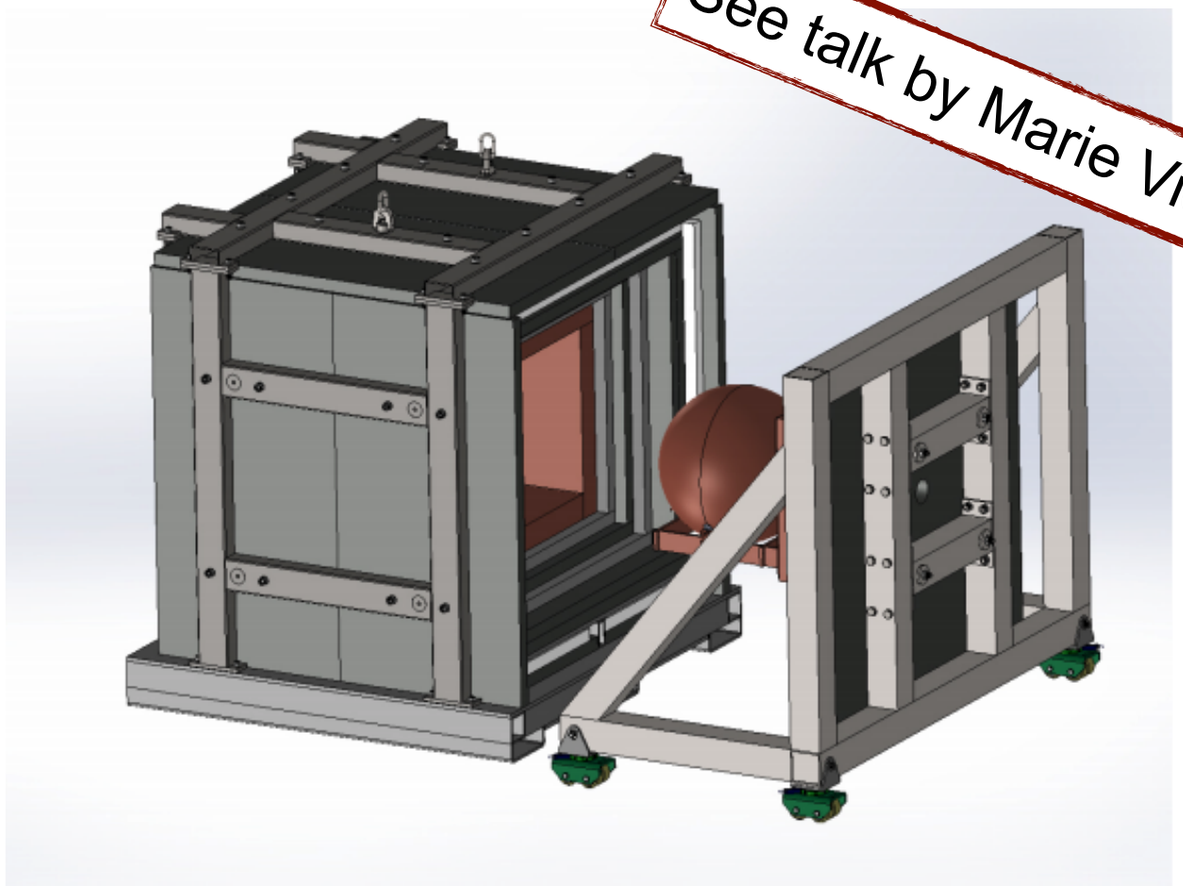




Coherent Elastic ν-Nucleus Scattering

- **CEvNS opens a window to investigation non-standard neutrino interactions**
  - First observations by COHERENT in NaI (2017) and Ar (2020)
  - Unique complementarity with DM searches as sensitivity reaches the neutrino floor
- **NEWS-G3: A low-threshold low-background sea-level facility**
  - Environmental and cosmogenic background studies towards reactor CEvNS studies
  - Shielding: Layers of pure copper, polyethylene, and lead, with active muon veto
  - Commissioning in 2021





Summary

NEWS-G probes uncharted DM territory using Spherical Proportional Counters

- Significant instrumentation advances enable exploration
  - ACHINOS, electroformation, …
- Several detectors scheduled for the coming years
- Eventually sensitivity could reach neutrino floor

Many physics opportunities: Nuclear (spin dependent and independent) and electron recoils, CEvNS, axions